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# United States Patent [19]

Jia

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[54] CONTRACTING/EXPANDING SELF-  
SEALING CRYOGENIC TUBE SEALS

[75] Inventor: Lin X. Jia, Upton, N.Y.

[73] Assignee: Florida Atlantic University, Boca  
Raton, Fla.

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[51] Int. Cl.<sup>6</sup> F16J 15/08

[52] U.S. Cl. 277/26; 277/170; 277/207 A;  
277/236; 285/917

[58] Field of Search 277/26, 27, 170,  
277/207 A, 236; 285/41, 187, 917, 918,  
369

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Primary Examiner—William A. Cuchlinski, Jr.

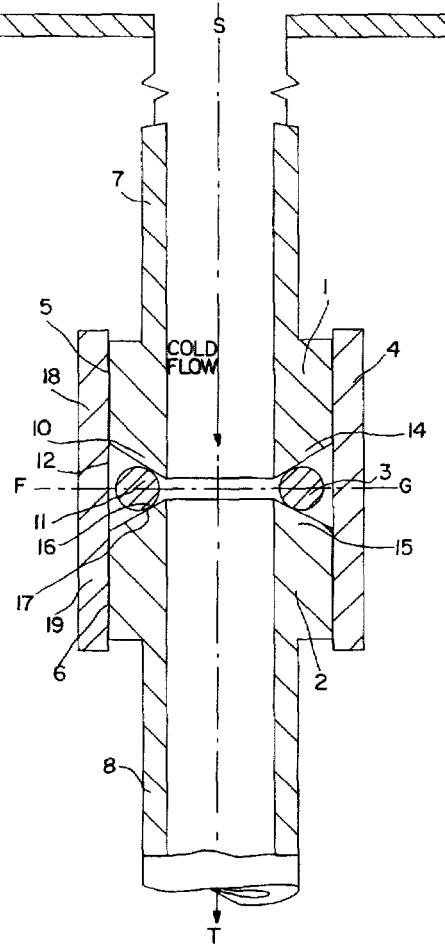
Assistant Examiner—John L. Beres

Attorney, Agent, or Firm—Saliwanchik, Lloyd & Saliwanchik

## [57] ABSTRACT

Contracting/expanding self-sealing cryogenic tube seals are disclosed which use the different properties of thermal contraction and expansion of selected dissimilar materials in accord with certain design criteria to yield self-tightening seals via sloped-surface sealing. The seals of the subject invention are reusable, simple to assemble, and adaptable to a wide variety of cryogenic applications.

15 Claims, 12 Drawing Sheets



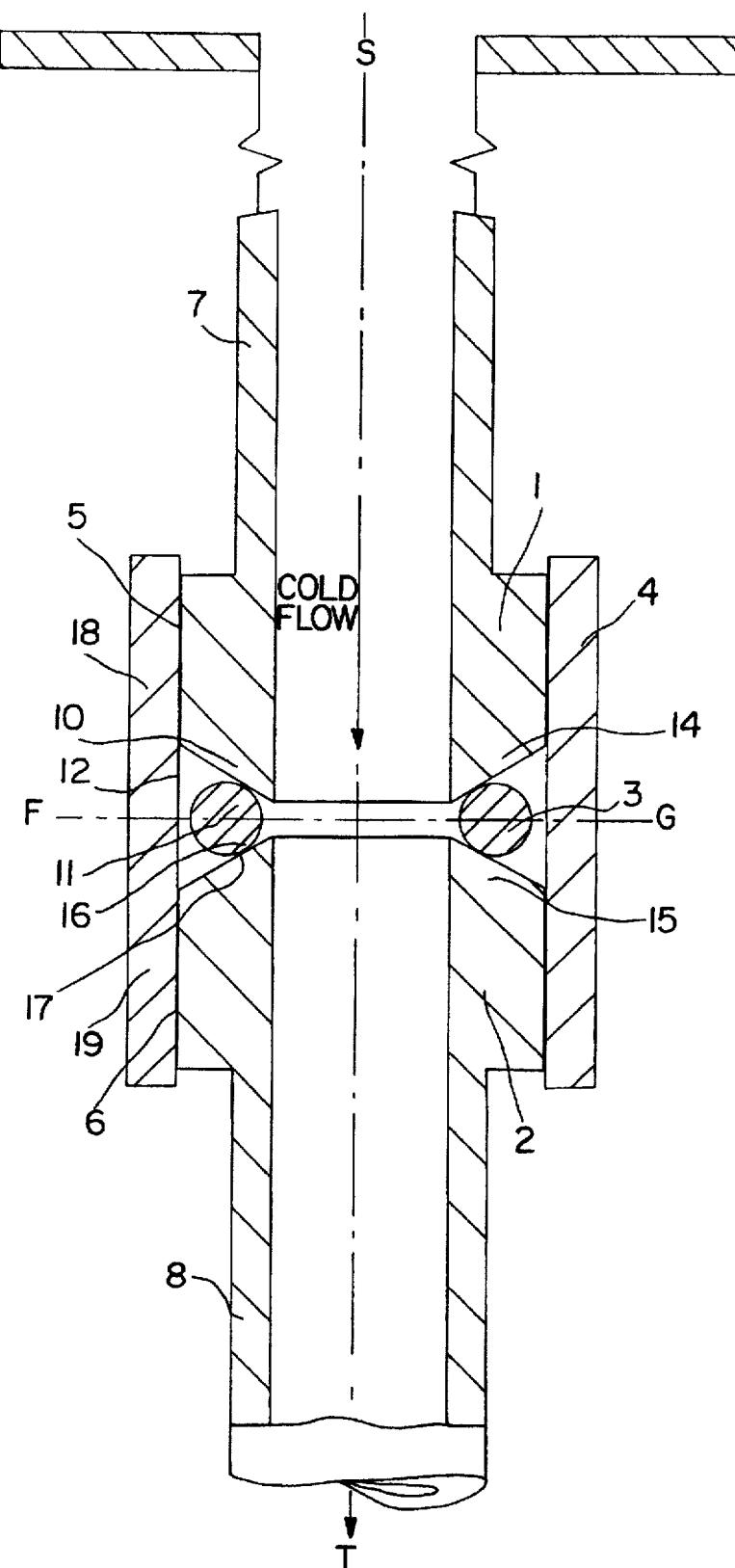


FIG. I

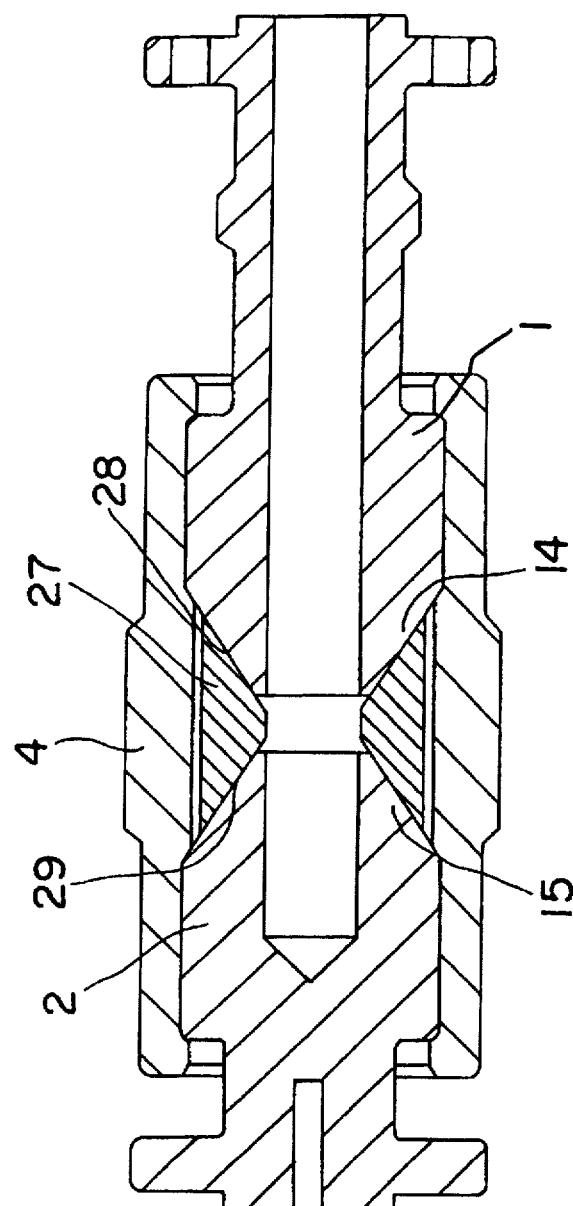


FIG. 2B

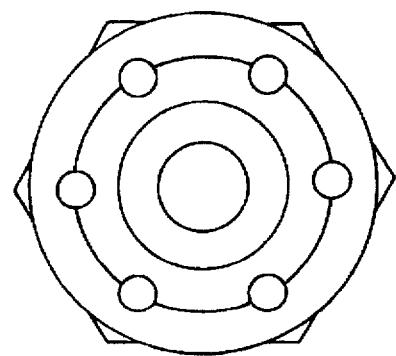


FIG. 2A

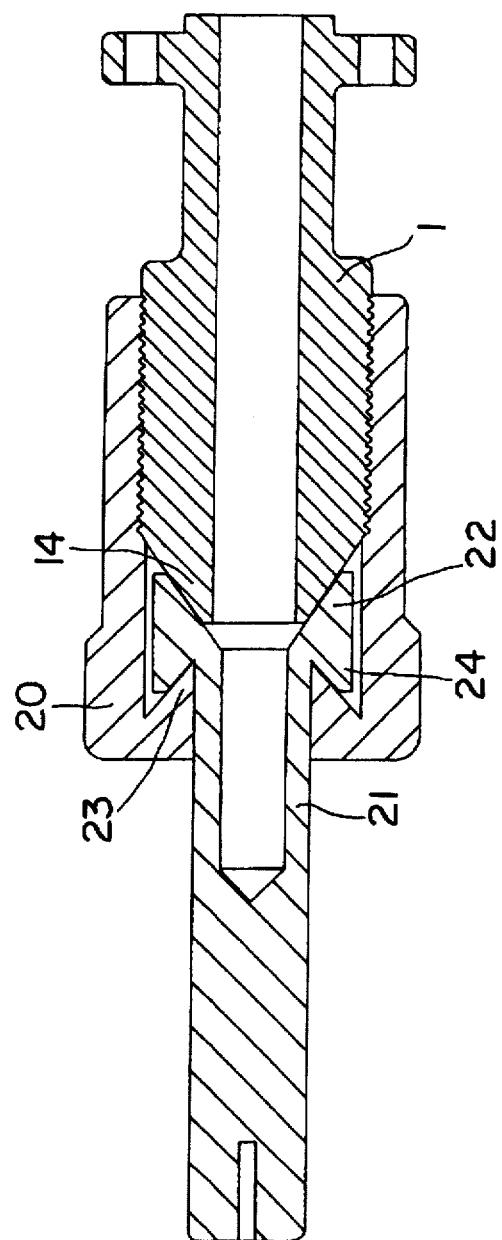


FIG. 3B

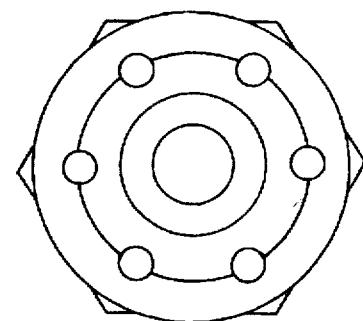


FIG. 3A

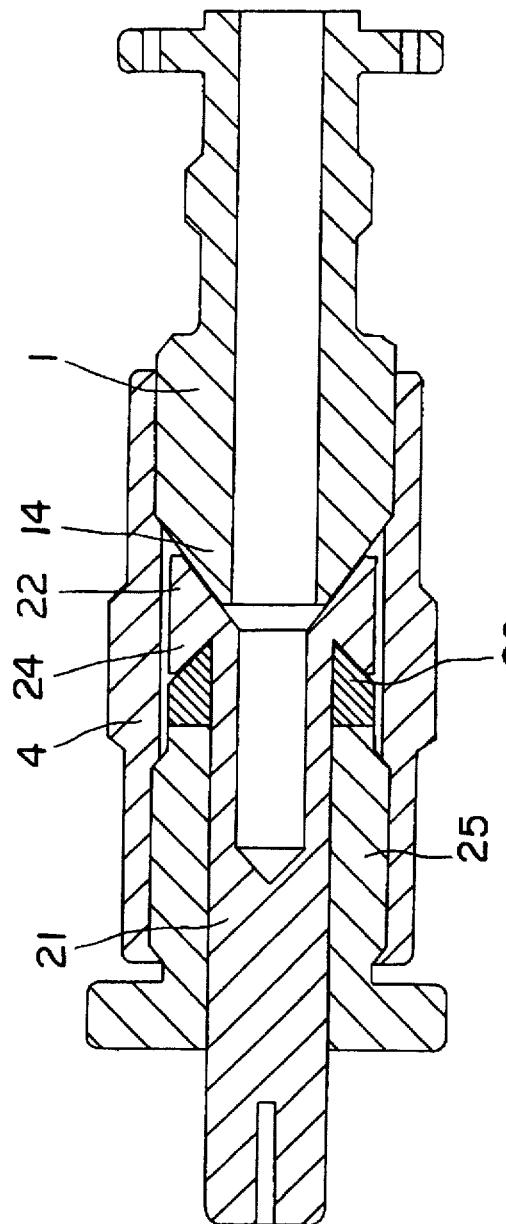


FIG. 4B

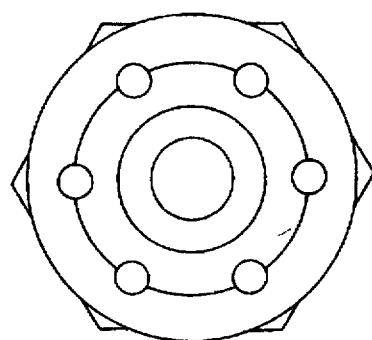


FIG. 4A

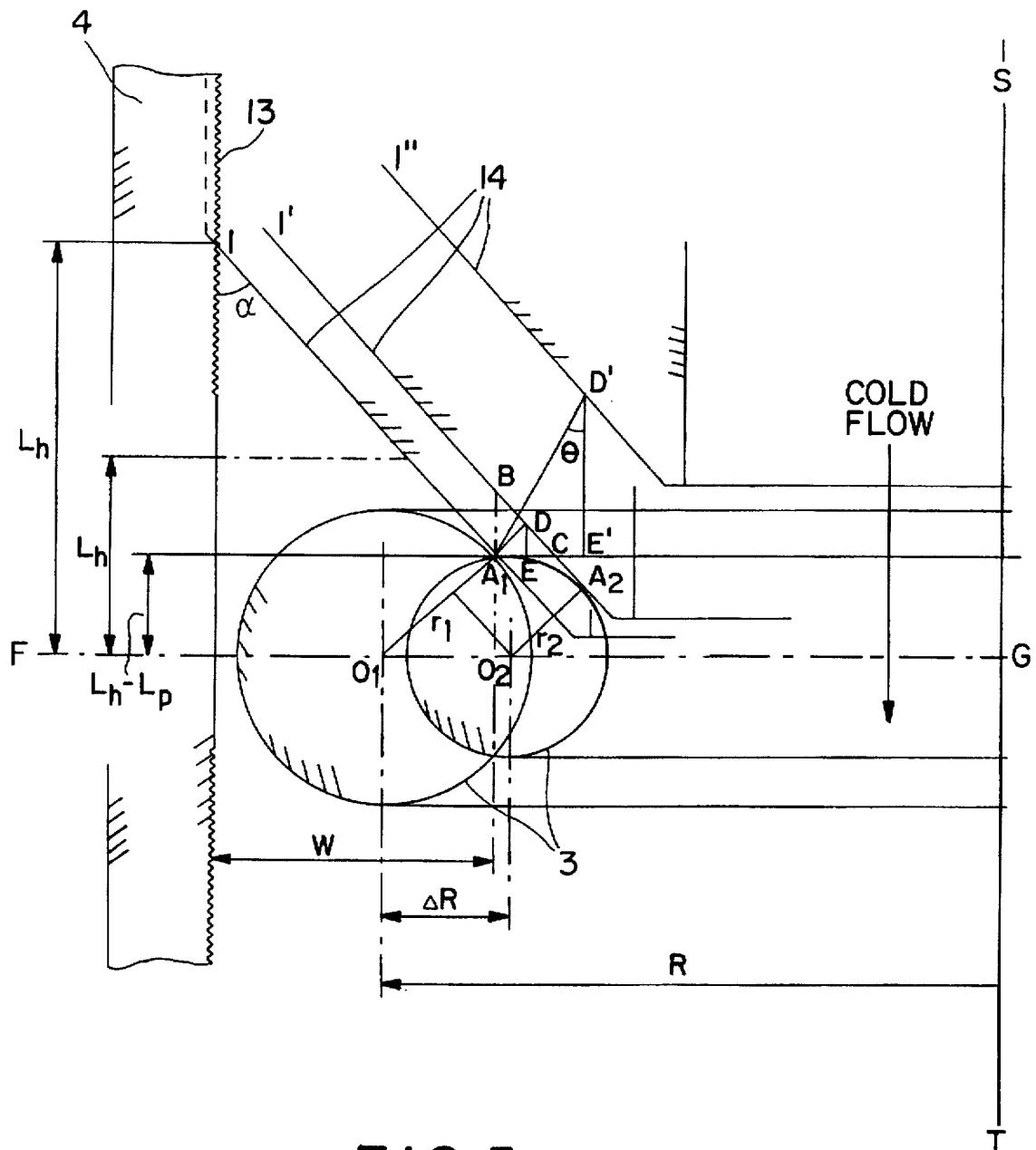


FIG. 5

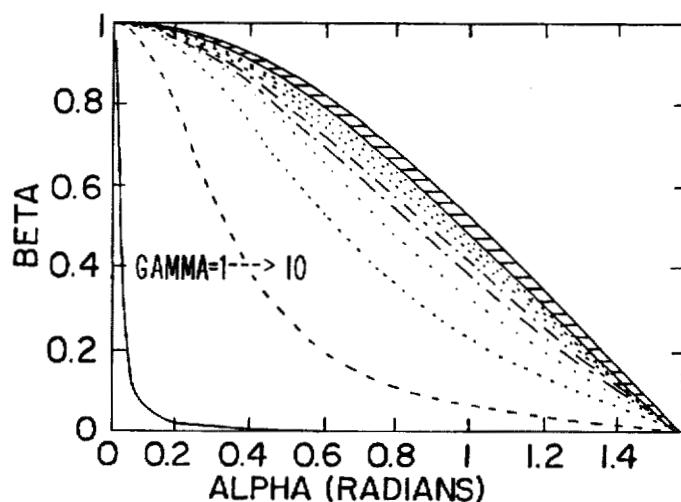


FIG.6A

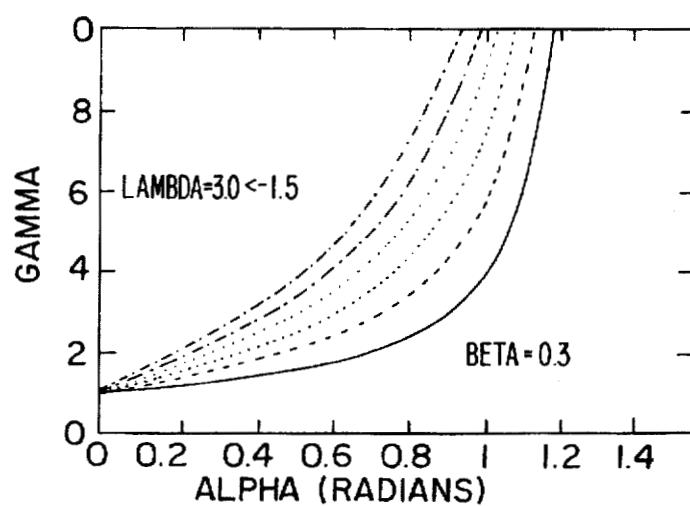


FIG.6B

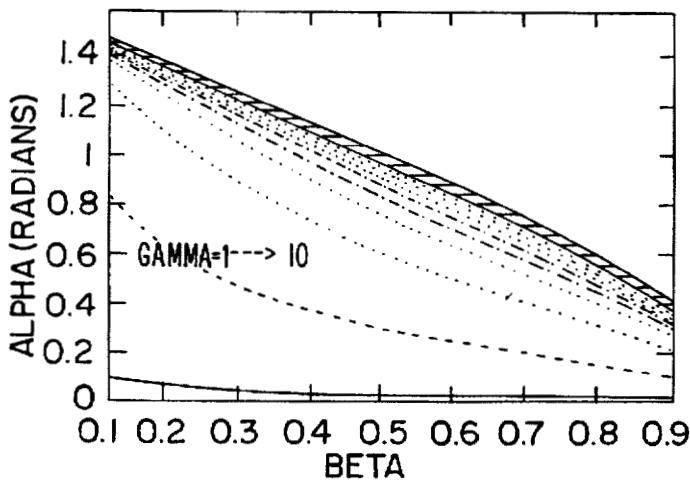


FIG.6C

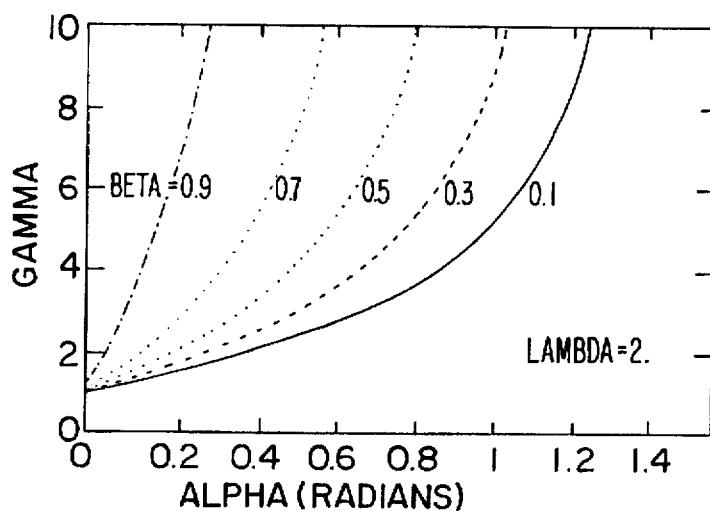


FIG. 6D

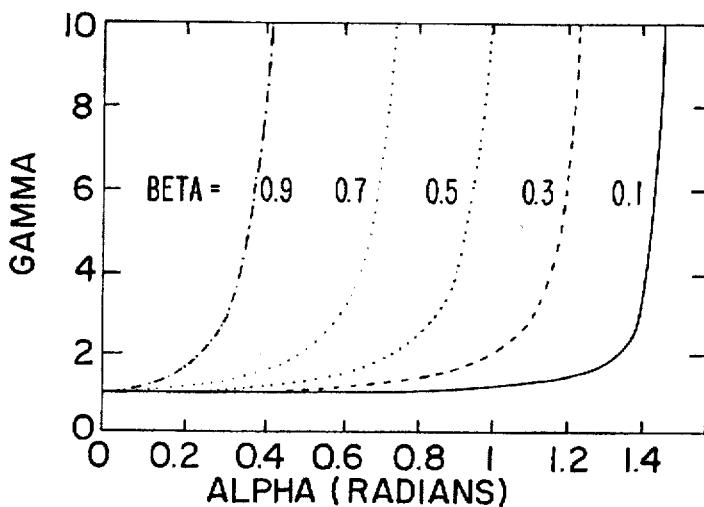


FIG. 6E

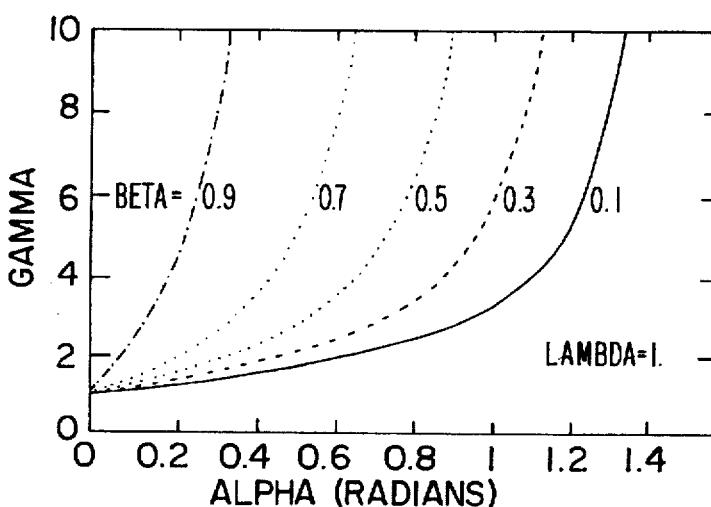


FIG. 6F

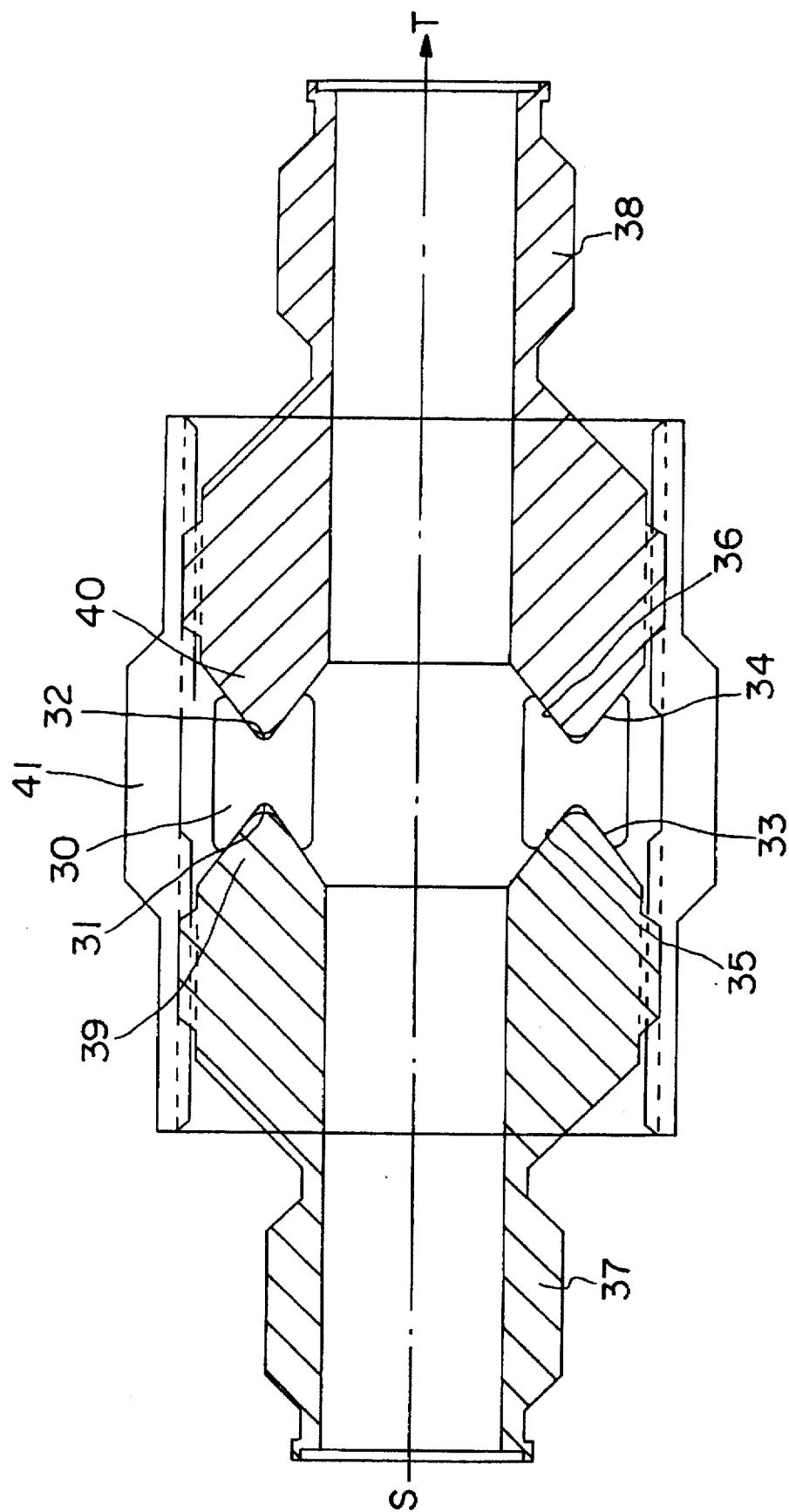


FIG. 7

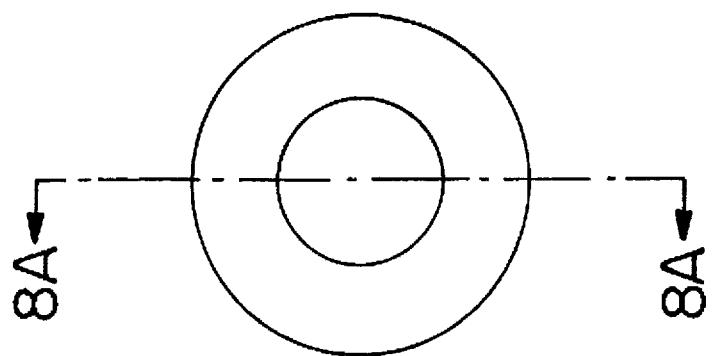


FIG. 8B

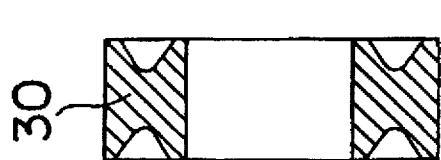


FIG. 8A

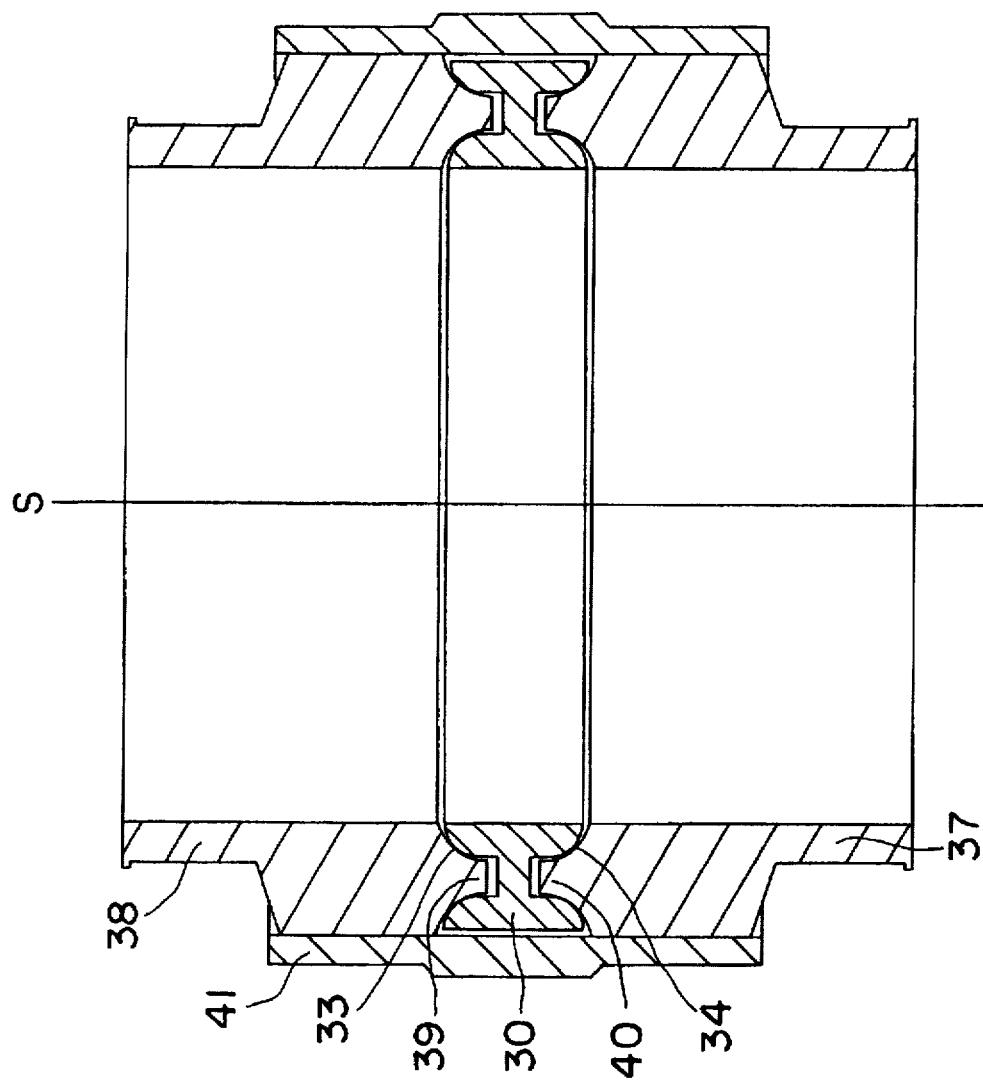


FIG. 9

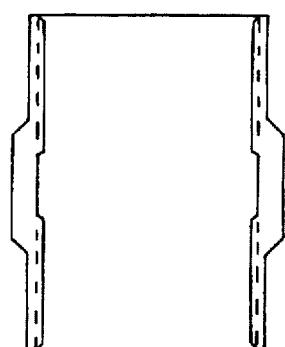


FIG. IIA

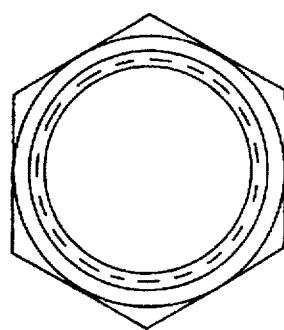


FIG. II B

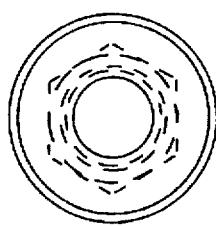


FIG. IOB

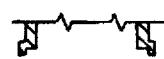


FIG. IOD

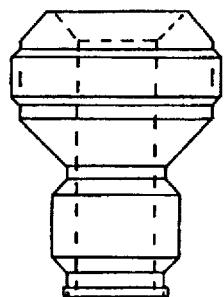


FIG. IOA

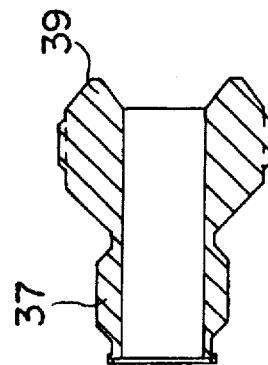


FIG. IOC

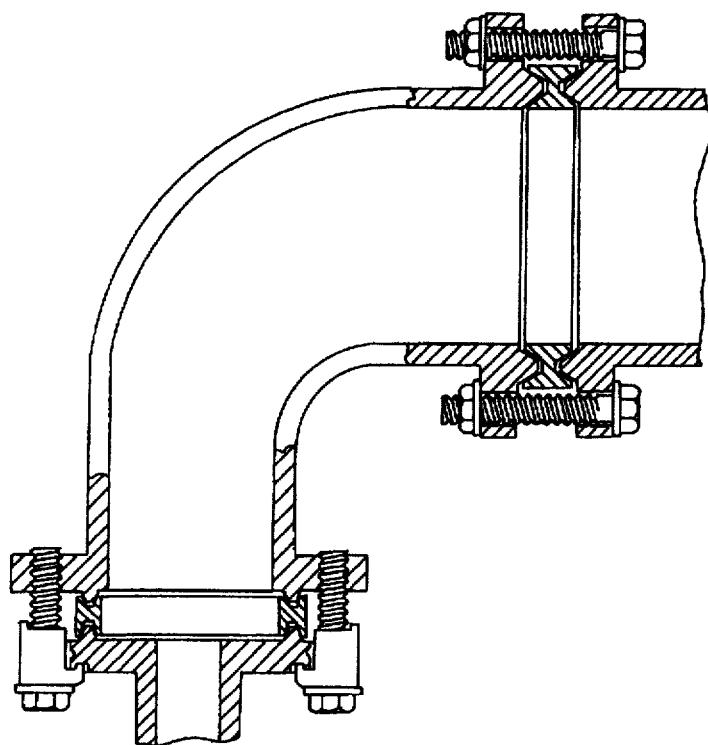


FIG. 12B

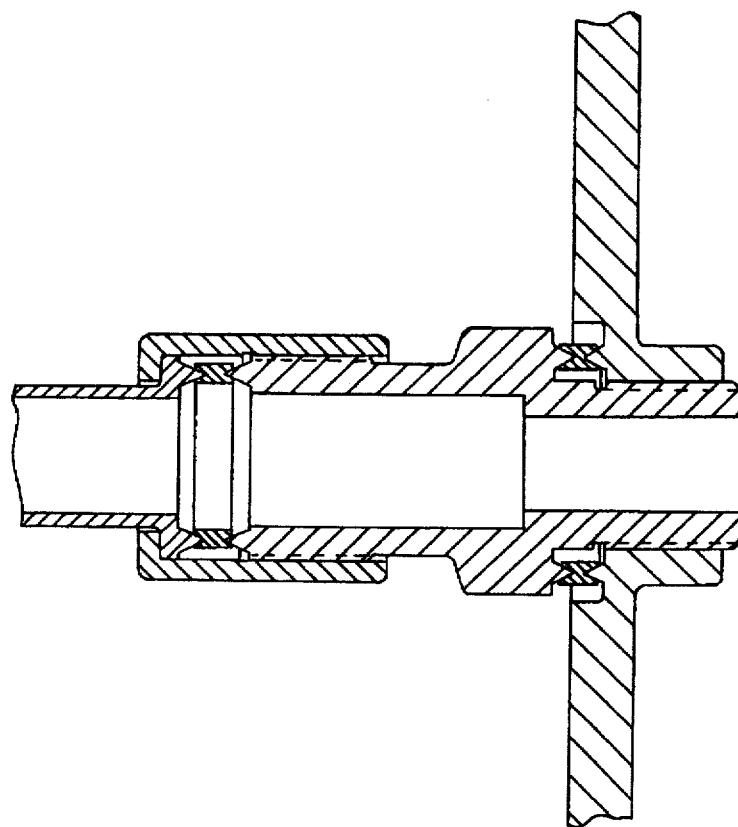


FIG. 12A

## CONTRACTING/EXPANDING SELF-SEALING CRYOGENIC TUBE SEALS

The subject invention was made with government support under a research project supported by NASA-Kennedy Space Center and under Contract No. NAS10-11569 and Research Grant No. NAG10-0083. The government has certain rights in this invention.

### BACKGROUND OF THE INVENTION

The rigorous conditions of very low operating temperatures coupled with high pressure impose extreme difficulties for controlling cryogen leakage from in-line tube fittings. The KC126 fitting, which has been used by NASA in the fuel lines of the space shuttle, has been found to leak. We have shown that the KC126 fitting leaks at 205K. and at 77K has a leak mass flux of  $1.28 \times 10^{-3}$  kg/min. See also Moore, Z., D. Capellin, A. Rodriguez, J. England (1988) "LH<sub>2</sub> TSM Leakage Problem," Interim Report: DM-MED-4, NASA, J.F.K. Space Center. Accordingly, there exists a need for an improved design of cryogenic seal for tube fittings such as those used in the space shuttle, and which is reusable and seals under extremes of low temperature and high pressure. Such a seal would have wide application in the cryogenic art.

The problem of sealing a joint between two interconnecting pieces that are designed to operate at cryogenic temperatures has been previously recognized. In part, this problem was addressed in U.S. Pat. No. 3,630,533, issued Dec. 28, 1971 to Butler et al., entitled "Dynamic Seal for Cryogenic Fluids." An additional problem addressed by Butler et al. is the high temperature sealing problem, which influenced Butler et al.'s design. Butler et al. used a circular sealing ring made from a fluorocarbon plastic material to seal two metal tubular couplings. The sealing ring is pressed onto a radially outward surface of one of the metal couplings. The sealing ring has a radially inward protruding annular rib which elastically and inelastically deforms as the sealing ring is pressed into place. This arrangement effects a sealing engagement between the sealing ring and the metal coupling at temperatures reported to be within the range of 70° F. to -423° F. At normal temperatures, the inner surface of the sealing ring is held in sealing engagement by the elastic preload induced by the initial interference press-fit and deformation of the protruding annular rib. In addition to the preload, a circumferential tension is generated in the sealing ring as the temperature decreases, because the sealing ring's coefficient of thermal expansion and contraction is greater than the coefficient of thermal expansion and contraction of the metal couplings. Thus, because of the differences in the expansion coefficients of the sealing ring and the metal coupling that it is pressed onto, the sealing engagement between these members of two different materials becomes tighter as the temperature decreases. However, in Butler et al.'s design, each time two metal tubular couplings are sealed together, the complex plastic sealing ring must be inelastically deformed into a particular configuration. Since the sealing ring is irreparably deformed by its installation, after separation of the two couplings for maintenance or other reasons, it is necessary to replace the sealing ring before the two couplings can be rejoined. Such a "use once and throw away" approach is wasteful, ultimately expensive, and troublesome if a replacement ring is not readily available. A coupling between two members which can be joined and separated, without requiring a new sealing ring each time, is needed.

### BRIEF SUMMARY OF THE INVENTION

The subject invention, contracting/expanding self-sealing cryogenic tube seals, are thermal-contraction controlled-action sealing and gripping devices which utilize the differences of the thermal contraction of selected dissimilar materials in a specially designed and composed structure to self-tighten the seal via sloped-surface sealing between coupled members as the temperature decreases from ambient temperature. "Sloped-surface sealing" means that the contact points creating the seal are not the result of contact of parallel surfaces. In one preferred embodiment, the cooling process causes the contraction of a sealing spacer, further gripping the member ends, and causes the contraction of a housing nut, further forcing the coupling member ends together, thereby taking advantage of sloped-surface sealing in a novel way and preventing leakage of the flowing cryogen.

The contracting/expanding self-sealing cryogenic tube seals are leak-free from room temperature to cryogenic temperatures as low as that of liquid helium and, unlike anything known in the art, provide easily remountable tube connections for high pressure and low temperature applications.

The contracting/expanding self-sealing cryogenic tube seal is a general purpose cryogenic tube seal. It provides reliable leak-free connections for the low/high pressure and low temperature working conditions in cryogenic applications. It can be easily applied to various cryogenic fittings and valves. Some basic advantages of contracting self-sealing cryogenic fittings are summarized as follows:

1. Applicable to any low temperatures and temperature cycling.
2. Works on most common magnetic/non-magnetic tube materials.
3. Seals on machined surfaces.
4. Does not reduce the flow area.
5. Works on vacuum as well as low or high pressures.
6. Simple in structure for production and handling.
7. Easy to use, similar to the standard SAE fittings.
8. Easy to assemble and disassemble.
9. Ability to reuse without special maintenance or replacement.
10. Not sensitive to the applied coupling torques.
11. Not sensitive to the moment from other components.
12. Not corrosive for common cryogen.
13. Applicable to most cryogenic tube connections.

Design criteria for contracting/expanding self-sealing cryogenic (CESSC) tube seals are taught which must be applied in accord with the subject invention, and which depend on the properties of selected materials as well as the configuration of the seal. These criteria, illustrated by the following examples, enable the construction by means well known in the art of a tremendous number of varying embodiments, all of which are based on the novel sloped-sealing concepts taught herein, as will be readily apparent to the skilled artisan.

### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 depicts a longitudinal section through a preferred embodiment of a contracting self-sealing cryogenic tube seal.

FIG. 2 depicts a longitudinal section through a variation of the embodiment depicted in FIG. 1, wherein the O-ring spacer has been replaced with a modified spacer.

FIG. 3 depicts a longitudinal section through an alternative embodiment of a contracting self-sealing cryogenic tube seal having only three components.

FIG. 4 depicts a longitudinal section through an alternative embodiment of the contracting self-sealing cryogenic tube seal.

FIG. 5 depicts the geometric analysis of cryogenic shrinkage of the components of the contracting self-sealing cryogenic tube seal.

FIG. 6 is a graphic representation of the design criteria for the contracting self-sealing cryogenic tube seal.

FIG. 7 depicts a longitudinal section through a preferred embodiment of a contracting/expanding self-sealing cryogenic tube seal.

FIG. 8 is a schematic drawing of an H-shaped spacer of a preferred embodiment of the contracting/expanding self-sealing cryogenic tube seal.

FIG. 9 depicts an H-shaped spacer of the contracting/expanding self-sealing cryogenic tube seal wherein the sloped surface sealing is accomplished via contact of curved surfaces.

FIG. 10 is a schematic drawing of a preferred embodiment of a coupling member of the contracting/expanding self sealing cryogenic tube seal.

FIG. 11 is a schematic drawing of a preferred embodiment of the housing nut of the contracting/expanding self sealing cryogenic tube seal.

FIG. 12 depicts various embodiments of the contracting/expanding self sealing cryogenic tube seal in potential operational configurations.

Table 1

#### DETAILED DISCLOSURE OF THE INVENTION

Following are examples which illustrate procedures, including the best mode, for practicing the invention. These examples should not be construed as limiting.

#### EXAMPLE 1

##### A Preferred Embodiment

In a preferred embodiment, as depicted in FIG. 1, the contracting self-sealing cryogenic tube seal consists of four basic components: metal coupling members 1 and 2, each having a male an-flare tube end 14 and 15, respectively, an O-ring spacer 3, and a housing nut 4. Housing nut 4 comprises internal threads 13 for threaded engagement with external threads 5 and 6 on coupling members 1 and 2, respectively. The O-ring spacer 3 rests between two male an-flare coupling members 1 and 2.

Various parts of contracting self-sealing cryogenic tube seals are made of dissimilar solid bar metals, thereby taking advantage of their different coefficients of thermal contraction. The materials for O-ring spacer 3 and housing nut 4 have higher values of the coefficient of thermal contraction than does the material used for coupling members 1 and 2. In the preferred embodiment, the components are axisymmetric (symmetric about an axis).

Assembly of the contracting self-sealing cryogenic tube seal depicted in FIG. 1 is a simple matter of engaging housing nut 4 with coupling member 1 until the an-flare tube end 14 of coupling member 1 is positioned approximately in the middle of housing nut 4, proximal to the lateral plane represented by segment FG. O-ring spacer 3 is then inserted into housing nut 4 until it contacts an-flare tube end 14 of

coupling member 1. Coupling member 2 is then engaged into housing nut 4 until an-flare tube end 15 is secured against O-ring spacer 3. The sloped surface of the an-flare tube ends allows for contraction of the spacer while ensuring that a tight seal is maintained.

In operation, cryogenic fluid begins to flow through the contracting self-sealing cryogenic tube fitting along longitudinal axis ST as depicted in FIG. 1. For ease of discussion, movement toward position S will be referred to as "upward"

10 and movement toward position T will be referred to as "downward;" movement toward axis ST will be referred to as "inward" and movement away from axis ST will be referred to as "outward." As the cryogenic fluid flows, the temperature of all parts of the contracting self-sealing cryogenic tube seal begins to decrease. Accordingly, the various parts of the tube seal shrink in size. Contact portion 10 at tube end 14 tends to shrink upward and inward. Contact portion 11 at O-ring spacer 3 tends to shrink downward and inward.

15 That portion 18 of housing nut 4, which is depicted above lateral plane FG, tends to shrink downward and inward, while housing nut portion 19, below plane FG, tends to shrink upward and inward. Because O-ring spacer 3 and housing nut 4 are made of materials having a larger coefficient of thermal contraction than are coupling members 1

20 and 2 (and thus tube ends 14 and 15), the inward shrinkage of O-ring spacer 3 tends to cause it to press even more tightly against tube ends 14 and 15. Similarly, shrinkage of housing nut 4 tends to force tube ends 14 and 15 toward each other, as well as providing a tighter engagement of threaded

25 portions 13, 5, and 6. Thus, the effects of thermal contraction will always maintain a leak-free seal in the contracting self-sealing cryogenic seal.

#### EXAMPLE 2

##### Some Alternative Embodiments

FIGS. 2, 3, and 4 depict exemplary alternative embodiments of the subject invention. To ensure proper sealing, contact surfaces of the components are axisymmetric. FIG.

40 2 depicts an embodiment similar to that depicted in FIG. 1 except that O-ring spacer 3 has been replaced with a flared spacer 27 having opposed female-flared contact surfaces 28 and 29, each having a complementary shape to tube ends 14 and 15, respectively, such that a tight seal is maintained therebetween in accord with the design criteria described hereinafter.

FIG. 3 depicts coupling member 1 with male an-flare tube end 14, coupling member 21 with female flare tube end 22, and housing nut 20, having a large bore at one end with

45 internal threaded means for receiving and engaging coupling member 1 and a smaller (step down) bore at the other end, which is just large enough to surround coupling member 21, but not large enough to allow female flare tube end 22 to pass through. The internal surface of the step-down end of

50 housing nut 20 defines a circumferential flange 23, radially sloping downward and outward. Housing nut 20 engages coupling member 1, and as housing nut 20 is tightened about coupling member 1, flange 23 engages a circumferential lip 24 on coupling member 21, lip 24 having a complementary

55 slope to that of flange 23 such that contact is maintained between lip 24 and flange 23, and pulls coupling member 21 such that the female flare tube end 22 of coupling member 21 is thereby brought into contact with male an-flare tube end 14 of coupling member 1, similar to the method by

60 which a garden hose is brought into contact with a spigot. Secured contact between tube end 14 and tube end 22 is thereby maintained in accord with the disclosed design

criteria. To maintain the sloped-surface seal of this embodiment leak-free at cryogenic temperatures, coupling member 21 and housing nut 20 are made of materials having a larger coefficient of thermal expansion than the material of coupling member 1, all in accord with the design criteria. For example, coupling member 21 and housing nut 20 may be made of copper, if coupling member 1 is stainless steel.

The embodiment depicted in FIG. 4 combines features of the embodiments depicted in FIGS. 1 and 3. Housing nut 4 is engaged with coupling member 1 until the an-flare tube end 14 of coupling member 1 is positioned approximately in the middle of housing nut 4. Housing nut 4 then engages collar 25, which has external threaded means for being engaged and secured by the internal threaded means of housing nut 4, and which also has a wedge end 26 which engages lip 24 on coupling member 21 and forces female flare tube end 12 into secured contact with male an-flare tube end 14. Thus, it can be seen that the collar and wedge component of this embodiment can be used with housing nut 4 to effectively replace the flange 23 and small bore end of housing nut 20 of the embodiment depicted in FIG. 3. To maintain the sloped-surface seal of this embodiment leak-free at cryogenic temperatures, collar 25 (having wedge end 26), as well as coupling member 1, are made of materials having a smaller coefficient of thermal expression than the material of housing nut 4 and coupling member 21 (having lip 24).

### EXAMPLE 3

#### Design Criteria of Contracting/Expanding Self-Sealing Cryogenic Seals

According to the theory of Gas Dynamics and the linear analysis of thermal contraction, some criteria for the design of contracting/expanding self-sealing cryogenic seals are given below:

(1) Design criteria for two components—tube and spacer:

$$\alpha < \cos^{-1} \left\{ \left[ \gamma_o + \left( \frac{\gamma_o - 1}{2\beta} \right)^2 \right]^{1/2} - \frac{\gamma_o - 1}{2\beta} \right\}$$

$$\beta < \frac{\gamma_o - 1}{\frac{\gamma_o}{\cos(\alpha)} - \cos(\alpha)}, \quad \gamma_o > \frac{1 - \beta \cos(\alpha)}{1 - \frac{\beta}{\cos(\alpha)}}$$

(2) Design criteria for three components—housing nut, tube-end, and spacer:

$$\gamma_o(T) > \frac{C_1(T)}{C_2}$$

where

$$C_1(T) = \sin \left[ \alpha + 0 \tan^{-1} \left( \frac{1 - \beta \cos \alpha}{\frac{\lambda}{\tan \alpha} (1 - \gamma_h(T)) - \gamma_h(T) \beta \sin \alpha} \right) \right]$$

$$C_2 = (\cos \alpha - \beta)$$

Referring to FIG. 5,  $\alpha$  is the an-flared angle of the tube ends.  $\beta$  is the radius ratio of O-ring spacer  $r_1/R$ .  $\lambda$  is the ratio of the thickness of tube-end to the radius of the spacer,  $w/R$ .  $\gamma_o$  ( $\gamma_o = \epsilon_o/\epsilon_p$ ) is the ratio of thermal contraction of the material used for the spacer to that of the tube ends.  $\gamma_h$  ( $\gamma_h = \epsilon_h/\epsilon_p$ ) is the ratio of thermal contraction of the material used for the housing-nut to that of the tube ends. The parameters,  $\alpha$ ,  $\beta$ ,

and  $\lambda$ , are the parameters of the seal geometry.  $\gamma_o$  and  $\gamma_h$  are the functions of temperature, which can be found from the tables of material properties and are well known in the art.

These criteria have been illustrated in the graphs of FIG. 5. 6. The physics of the thermal contracting process or the thermal and geometric effects of the contracting/expanding self-sealing cryogenic seal is revealed by these criteria. The contracting/expanding self-sealing cryogenic seal is predictable in its response to temperature fluctuations—it consistently fulfills the promise of self-sealing for cryogenic applications.

A linear approximation of the sealing process in a thermal-contraction controlled-action seal by a simple geometric analysis was used to calculate design parameters of the contracting/expanding self-sealing cryogenic seal. The contracting self-sealing cryogenic tube seals exemplified herein were designed in accord with this analysis and have successfully passed a series of tests in the cryogenic leak test system with a temperature drop from room temperature down to the liquid helium temperature in the Cryogenic Laboratory of Florida Atlantic University.

Shown in FIG. 5 is the cross-section of an O-ring spacer seated between an-flared tube ends with axial angle,  $\alpha$ , before and after cooling period. Both O-ring spacer and tube end, which have different coefficients of thermal expansion, shrink axisymmetrically in the cooling process.  $A_1$  and  $A_2$  are two contact points of the mating parts before and after cooling. Because of the thermal contraction, the original contact point,  $A_1$ , in the tube end moves to  $D$ , with a radial shrinkage,  $\Delta t = A_1 E$ , and an axial shrinkage,  $\Delta L = ED$ .

A maximum value of the shrinkage of the tube end in axial direction,  $\Delta L$ , can be obtained if presuming a zero-thermal-stress condition, which means free contracting of both O-ring spacer and tube end without losing contact with each other. It is apparent that if the actual axial shrinkage of the tube end is larger than the zero-thermal-stress shrinkage,  $\Delta L$ , the contracting self-sealing cryogenic seal will never achieve a leak-free seal.

40 From the geometry in FIG. 5, if we let  $\Delta L' = A_1 B$  and  $\Delta t' = A_1 C$ , then

$$\frac{\Delta L}{\Delta L'} = \frac{\Delta t - \Delta t'}{\Delta t'}$$

45

and  $\Delta t' = \Delta L' \tan \alpha$ , we have

$$\Delta L = \Delta L' - \frac{\Delta t}{\tan \alpha} \quad (1)$$

50 and also,

$$\Delta L' \sin \alpha + r_1 = \Delta R \cos \alpha + r_2$$

55 we have,

$$\Delta L' = \frac{\Delta R}{\tan \alpha} - \frac{\Delta r}{\sin \alpha} \quad (2)$$

where  $\Delta r = r_1 - r_2$ . Combining Eq. (1) and (2),

$$\Delta L = \frac{1}{\tan \alpha} \left( \Delta R - \Delta t - \frac{\Delta r}{\cos \alpha} \right) \quad (3)$$

Assuming a linear contraction as a first approximation, i.e.,  $\Delta R = \epsilon_o R$ , since  $r$  is much smaller than  $R$ , and  $\Delta r = \epsilon_o r_1$  and  $\Delta t = \epsilon_p (R - r_1 \cos \alpha)$  for the same approximation, where  $\epsilon$  and  $\epsilon_p$  are the coefficients of thermal expansion of O-ring spacer and tube end, respectively. Substituting  $\Delta R$ ,  $\Delta t$ , and

$\Delta r$  into Eq. (3), we have,

$$\Delta L = \frac{1}{\tan \alpha} \left[ R(\epsilon_o - \epsilon_p) - r_1 \left( \frac{\epsilon_o}{\cos \alpha} - \epsilon_p \cos \alpha \right) \right] \quad (4)$$

Let  $\gamma = \epsilon_o/\epsilon_p$ , and  $\beta = r_1/R$ , we can rewrite Eq. (4) as

$$\Delta L = \frac{R\epsilon_p}{\tan \alpha} \left[ \gamma \left( 1 - \frac{\beta}{\cos \alpha} \right) + \beta \cos \alpha - 1 \right] \quad (5)$$

The maximum axial shrinkage of tube end,  $\Delta L$ , from the above equation, is a function of three parameters,  $\alpha$ ,  $\beta$ , and  $\gamma$ , where  $\alpha$  is the an-flared angle of the tube end,  $\beta$  is the radius ratio of the O-ring spacer, and  $\gamma$  is the ratio of thermal properties of material used for two mating parts.

In order to have a positive value of  $\Delta L$ , the term in brackets must be positive, which leads to three design criteria for three parameters, each one depending on the other two, which are given as follows:

$$\gamma > \frac{1 - \beta \cos \alpha}{\beta} \quad (A)$$

$$\beta < \frac{\gamma - 1}{\frac{\gamma}{\cos \alpha} - \cos \alpha} \quad (B)$$

$$\alpha < \cos^{-1} \left\{ \left[ \gamma + \left( \frac{\gamma - 1}{2\beta} \right)^2 \right]^{1/2} - \frac{\gamma - 1}{2\beta} \right\} \quad (C)$$

According to the above criteria,  $\alpha$  and  $\beta$  do not have lower limitations except for the negative values, which are meaningless for an O-ring seal. The lower limitations actually depend on the strength of the materials. The minimum value of  $\alpha$  depends on the requirement for the wall thickness of the tube end. The minimum value of  $\beta$  depends on the requirement for the radius of the cross section of the O-ring spacer. The graphs of FIG. 6 represent possible values for  $\alpha$ ,  $\beta$ , and  $\gamma$  that can be used for the design of contracting self-sealing cryogenic seal. In Table 1, a dimensionless parameter of  $\Delta L/R\epsilon_p$ , is given which is computed from Eq. (5) for the convenience of applications. For example, if we choose  $\alpha=35^\circ$ , and  $\beta=0.3$ , then  $\gamma$  must be larger than 1.2. If we chose  $\gamma=6$  (for copper O-ring and invar tube end), we have  $\Delta L/R\epsilon_p=4.5$ . If  $R=8$  mm, and  $\epsilon_p=0.06\%$  (invar at 6K), the maximum promising axial shrinkage,  $\Delta L=0.022$  mm. This is an approximate value for the tested contracting self-sealing cryogenic seal at liquid helium temperature.

#### EXAMPLE 4

##### Selection of Materials for Contracting/Expanding Self-Sealing Cryogenic Seals

The function of a contracting/expanding self-sealing cryogenic seal relies upon the differences of the thermal contractions of dissimilar materials in a specially composed structure which, in a novel, advantageous manner uses the concept of sloped-surface sealing. The selection of materials is basically determined by the nature of thermal contraction of the materials used for each of the components. The contracting/expanding self-sealing cryogenic seal works only if it is designed to meet the criteria which are dependent upon not only the thermal properties of materials, but also the geometric parameters. The selection of the materials, therefore, is not an independent factor in order to achieve a self-sealing purpose. It must be considered together with the geometric parameters of the components of the seal. In this regard, the contracting self-sealing cryogenic seal is an integrated unit.

One of the possible combinations is given as follows: The material for tube ends is commonly the same as that for the tubing bodies. For cryogenic situations, stainless steel is a commonly-used material for tubing bodies. Therefore, among other common engineering materials, in the embodiment depicted in FIG. 1, copper is one of the possible choices for the housing nut and the O-ring spacer, used with the stainless steel tube ends. However, the geometric configuration must meet the contracting self-sealing cryogenic criteria disclosed above with the given parameter of thermal contraction ratio calculated for copper to stainless steel.

#### EXAMPLE 5

##### Test Results of Various Embodiments of Contracting Self-Sealing Cryogenic Seal

The contracting self-sealing cryogenic seals have passed a series of tests in the cryogenic leak test system at Florida Atlantic University. The detailed information of the cryogenic leak test system is given in Jia, L. X., D. Moslemian, W. L. Chow (1992) "Cryogenic leak testing of tube fittings/valves," *Cryogenics*, 32(9):833-839, which is incorporated herein by reference thereto. The tests were conducted under two different temperature levels, LN<sub>2</sub> temperature ( $\approx 77$ K), and LHe temperature ( $\approx 4$ K).

For the leak test under LN<sub>2</sub> temperature, the highest internal pressure against the external vacuum applied to this seal has been  $31 \times 10^5$  Pa, nearly two times the working pressure in the space shuttle. The test lasted about ten hours without showing any signs of leak from vacuum gauges at pressure of  $5 \times 10^{-4}$  Bar within the sample chamber. In another test, initial pressurization was to  $27.1 \times 10^5$  Pa. As the temperature dropped to 140K, additional gaseous helium was supplied to increase the internal pressure from  $12 \times 10^5$  Pa to  $26.2 \times 10^5$  Pa. When the equilibrium temperature of 77K was reached, internal pressure was reduced down to  $17.2 \times 10^5$  Pa and kept under this condition for another 10 hours. Throughout the testing period, no pressure increase was detected in the evacuated sample chamber used to house the seal.

For the leak test under LHe temperature, a constant internal pressure of  $27.1 \times 10^5$  Pa against the external vacuum was applied to the contracting self-sealing cryogenic tube seal. The test lasted 5 hours at the temperature of 4.5K~6.9K without showing any signs of leak from vacuum gauges at pressure of  $1 \times 10^{-6}$  Bar within the sample chamber. The tests on the contracting self-sealing cryogenic tube seals at LHe temperature indicated that it is feasible to develop a new series of cryogenic tube seals for the LH<sub>2</sub> transfer lines of the space shuttle, as well as for other cryogenic applications, based on the novel sloped-sealing technology taught herein.

#### EXAMPLE 6

##### Contracting/Expanding Self-Sealing Cryogenic Seal

The concept for a contracting self-sealing cryogenic tube seal can be extended for a special application where a wide range and high rate of temperature cycling is a significant feature of the working condition. A contracting/expanding self-sealing cryogenic tube fitting is schematically shown in FIG. 7. With larger thermal contraction and thermal expansion coefficients, the shrinking or expanding displacement of the spacer caused by temperature cycling always tends to prevent the appearance of any possible leak gap between the tube ends and the spacer, no matter whether the working temperature is decreasing or increasing. A similar analysis

for a contracting/expanding self-sealing cryogenic seal can be easily obtained as described above by considering an additional reverse thermal process of temperature increase.

In a contracting/expanding self-sealing cryogenic seal as depicted in FIG. 7, the spacer 30 has an H-shaped cross-section, having opposed V-shaped female sloped-sealing surfaces 31 and 32 at each end which contact the complementary sloped male an-flare tube ends 39 and 40, respectively, of the coupling members 37 and 38. The male angle of the tube end is made slightly larger than the female angle of the corresponding surface of the spacer 30. A similar H-shaped spacer/seal is depicted in FIG. 9, wherein the sloped surface sealing is accomplished by contact of curved surfaces. When temperature is decreased, the outwardmost contact surfaces 33 and 34 of the spacer 30 will tightly grip the tube ends 39 and 40. When temperature is increased, the inside contact surfaces 35 and 36 of the spacer 30 will tightly press against the tube ends 39 and 40. Therefore, a tight seal is achieved under the temperature cycling condition. Since the temperature changes in two opposite directions, the thermal behavior of the housing nut 41 no longer contributes consistently for tube sealing during the temperature cycling. Therefore, in a preferred embodiment, the material for the housing nut 41 has a smaller coefficient of thermal contraction (or expansion) than does the spacer 30. The material for coupling members 37 and 38 also has a smaller coefficient of thermal expansion than does that of spacer 30. The selection of materials for the spacer 30 and tube ends 39 and 40 of contracting/expanding self-sealing cryogenic seals follows the same design criteria given above. In a preferred embodiment, the subject seal, seemingly sophisticated, surprisingly simply solves sometimes severe system seepage substantially superior to standard space shuttle seals by specially-selected, securely sandwiched, sloped-surface spacers snugly surrounding stainless steel surfaces shown self-sealing by sequential shrinking and swelling.

One preferred embodiment of the contracting/expanding self-sealing cryogenic seal was fabricated for use in the LH<sub>2</sub> lines of the space shuttle at the JFK Space Center. The H-shaped spacer 30 (see FIGS. 7 and 8) has a larger thermal expansion coefficient than that of the tube ends 39 and 40 between which it is sandwiched. Shrinkage or expansion of this spacer always tends to prevent the formation of any possible leaking gap between the tube ends and the spacer, regardless of whether the working temperature is decreasing or increasing. The contracting/expanding self-sealing cryogenic tube seal provides leak-free and easily remountable tube connections from temperatures as high as the component materials can withstand to cryogenic temperatures as low as that of liquid helium, and under pressures varying from vacuum to several hundred psi or more. The seal is especially effective in applications where a wide range and high rate temperature cycling are significant features of the working conditions. The seal can be easily integrated into all kinds of cryogenic tubing components, such as fittings and valves. Several possible configurations which employ the contracting/expanding self-sealing cryogenic tube seal are shown in FIG. 12. The contracting/expanding self-sealing cryogenic seal has passed the temperature cycling test: first cooled down from 296K to 12K, then heated up to 300K within 20 minutes, and then cooled down again to 77K, while the pressure maintained 400 psig, without showing any sign of leak.

It should be understood that the examples and embodiments described herein are for illustrative purposes only and that various modifications or changes in light thereof will be

suggested to persons skilled in the art and are to be included within the spirit and purview of this application and the scope of the appended claims.

TABLE 1

Design Parameters for CSSC Tube Fitting, ( $d_1 = \Delta L/R_{e_p}$ ).				
	gama(beta = 0.1000000)	alfa = 5 >	1.000848	
10	dl( 1.000848	0.1000000	5 )=	0.0000000E + 00
	dl( 1.500848	0.1000000	5 )=	5.141342
	dl( 2.000848	0.1000000	5 )=	10.28268
	dl( 2.500848	0.1000000	5 )=	15.42402
	dl( 3.000848	0.1000000	5 )=	20.56536
	dl( 3.500848	0.1000000	5 )=	25.70670
	dl( 4.000848	0.1000000	5 )=	30.84805
	dl( 4.500848	0.1000000	5 )=	35.98938
	dl( 5.000848	0.1000000	5 )=	41.13073
	dl( 5.500848	0.1000000	5 )=	46.27207
15	dl( 6.000848	0.1000000	5 )=	51.41341
	gama(beta = 0.1000000)	alfa = 10 >	1.003408	
	dl( 1.003408	0.1000000	10 )=	0.0000000E + 00
	dl( 1.503408	0.1000000	10 )=	2.547703
	dl( 2.003408	0.1000000	10 )=	5.095405
	dl( 2.503408	0.1000000	10 )=	7.643107
	dl( 3.003408	0.1000000	10 )=	10.19081
	dl( 3.503408	0.1000000	10 )=	12.73851
	dl( 4.003408	0.1000000	10 )=	15.28621
	dl( 4.503408	0.1000000	10 )=	17.83392
20	dl( 5.003408	0.1000000	10 )=	20.38162
	dl( 5.503408	0.1000000	10 )=	22.92932
	dl( 6.003408	0.1000000	10 )=	25.47702
	gama(beta = 0.1000000)	alfa = 15 >	1.007736	
	dl( 1.007736	0.1000000	15 )=	0.0000000E + 00
	dl( 1.507736	0.1000000	15 )=	1.672840
	dl( 2.007736	0.1000000	15 )=	3.345681
	dl( 2.507736	0.1000000	15 )=	5.018521
	dl( 3.007736	0.1000000	15 )=	6.691361
	dl( 3.507736	0.1000000	15 )=	8.364202
25	dl( 4.007736	0.1000000	15 )=	10.03704
	dl( 4.507736	0.1000000	15 )=	11.70988
	dl( 5.007736	0.1000000	15 )=	13.38272
	dl( 5.507736	0.1000000	15 )=	15.05556
	dl( 6.007736	0.1000000	15 )=	16.72840
	gama(beta = 0.1000000)	alfa = 20 >	1.013931	
	dl( 1.013931	0.1000000	20 )=	0.0000000E + 00
	dl( 1.513931	0.1000000	20 )=	1.227548
	dl( 2.013931	0.1000000	20 )=	2.455097
	dl( 2.513931	0.1000000	20 )=	3.682646
30	dl( 3.013931	0.1000000	20 )=	4.910194
	dl( 3.513931	0.1000000	20 )=	6.137743
	dl( 4.013931	0.1000000	20 )=	7.365292
	dl( 4.513931	0.1000000	20 )=	8.592841
	dl( 5.013931	0.1000000	20 )=	9.820390
	dl( 5.513931	0.1000000	20 )=	11.04794
	dl( 6.013931	0.1000000	20 )=	12.27549
	gama(beta = 0.1000000)	alfa = 25 >	1.022151	
	dl( 1.022151	0.1000000	25 )=	0.0000000E + 00
35	dl( 1.522151	0.1000000	25 )=	0.9539434
	dl( 2.022151	0.1000000	25 )=	1.907887
	dl( 2.522151	0.1000000	25 )=	2.861830
	dl( 3.022151	0.1000000	25 )=	3.815774
	dl( 3.522151	0.1000000	25 )=	4.769717
	dl( 4.022151	0.1000000	25 )=	5.723660
	dl( 4.522151	0.1000000	25 )=	6.677603
	dl( 5.022151	0.1000000	25 )=	7.631547
	dl( 5.522151	0.1000000	25 )=	8.585490
	dl( 6.022151	0.1000000	25 )=	9.539434
40	gama(beta = 0.1000000)	alfa = 30 >	1.032636	
	dl( 1.032636	0.1000000	30 )=	0.0000000E + 00
	dl( 1.532636	0.1000000	30 )=	0.7660255
	dl( 2.032636	0.1000000	30 )=	1.532051
	dl( 2.532636	0.1000000	30 )=	2.298077
	dl( 3.032636	0.1000000	30 )=	3.064102
45	dl( 3.532636	0.1000000	30 )=	3.830127
	gama(beta = 0.1000000)	alfa = 50 >	1.062500	
	dl( 1.062500	0.1000000	50 )=	0.0000000E + 00
	dl( 1.562500	0.1000000	50 )=	1.625000
	dl( 2.062500	0.1000000	50 )=	3.250000
	dl( 2.562500	0.1000000	50 )=	4.875000
50	dl( 3.062500	0.1000000	50 )=	6.500000
	dl( 3.562500	0.1000000	50 )=	8.125000
	dl( 4.062500	0.1000000	50 )=	9.750000
	dl( 4.562500	0.1000000	50 )=	11.375000
	dl( 5.062500	0.1000000	50 )=	13.000000
	dl( 5.562500	0.1000000	50 )=	14.625000
55	dl( 6.062500	0.1000000	50 )=	16.250000
	gama(beta = 0.1000000)	alfa = 60 >	1.077000	
	dl( 1.077000	0.1000000	60 )=	0.0000000E + 00
	dl( 1.577000	0.1000000	60 )=	1.754000
	dl( 2.077000	0.1000000	60 )=	3.508000
	dl( 2.577000	0.1000000	60 )=	5.262000
60	dl( 3.077000	0.1000000	60 )=	7.016000
	dl( 3.577000	0.1000000	60 )=	8.770000
	dl( 4.077000	0.1000000	60 )=	10.524000
	dl( 4.577000	0.1000000	60 )=	12.278000
	dl( 5.077000	0.1000000	60 )=	14.032000
	dl( 5.577000	0.1000000	60 )=	15.786000

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, ( $d_1 = \Delta L/R_{\epsilon_p}$ ).						
dl(	4.032636	0.1000000	30	=	4.596153	
dl(	4.532636	0.1000000	30	=	5.362179	
dl(	5.032636	0.1000000	30	=	6.128204	
dl(	5.532636	0.1000000	30	=	6.894230	
dl(	6.032636	0.1000000	30	=	7.660254	
gama(beta = 0.1000000 alfa = 35) >	1.045747					
gama	beta	alfa				
dl(	1.045747	0.1000000	35	=	0.0000000E + 00	
dl(	1.545747	0.1000000	35	=	0.6269017	
dl(	2.045747	0.1000000	35	=	1.253803	
dl(	2.545747	0.1000000	35	=	1.880705	
dl(	3.045747	0.1000000	35	=	2.507607	
dl(	3.545747	0.1000000	35	=	3.134508	
dl(	4.045747	0.1000000	35	=	3.7611410	
dl(	4.545747	0.1000000	35	=	4.388311	
dl(	5.045747	0.1000000	35	=	5.015213	
dl(	5.545747	0.1000000	35	=	5.642115	
dl(	6.045747	0.1000000	35	=	6.269017	
gama(beta = 0.1000000 alfa = 40) >	1.062034					
gama	beta	alfa				
dl(	1.062034	0.1000000	40	=	-7.1034052E - 08	
dl(	1.562034	0.1000000	40	=	0.5180907	
dl(	2.062034	0.1000000	40	=	1.036181	
dl(	2.562034	0.1000000	40	=	1.554272	
dl(	3.062034	0.1000000	40	=	2.072362	
dl(	3.562034	0.1000000	40	=	2.590453	
dl(	4.062034	0.1000000	40	=	3.108544	
dl(	4.562034	0.1000000	40	=	3.626635	
dl(	5.062034	0.1000000	40	=	4.144725	
dl(	5.562034	0.1000000	40	=	4.662816	
dl(	6.062034	0.1000000	40	=	5.180906	
gama(beta = 0.1000000 alfa = 45) >	1.082358					
gama	beta	alfa				
dl(	1.082358	0.1000000	45	=	0.0000000E + 00	
dl(	1.582358	0.1000000	45	=	0.4292893	
dl(	2.082358	0.1000000	45	=	0.8585786	
dl(	2.582358	0.1000000	45	=	1.287868	
dl(	3.082358	0.1000000	45	=	1.717157	
dl(	3.582358	0.1000000	45	=	2.146446	
dl(	4.082358	0.1000000	45	=	2.575736	
dl(	4.582358	0.1000000	45	=	3.005025	
dl(	5.082358	0.1000000	45	=	3.434314	
dl(	5.582358	0.1000000	45	=	3.863604	
dl(	6.082358	0.1000000	45	=	4.292893	
gama(beta = 0.1000000 alfa = 50) >	1.108113					
gama	beta	alfa				
dl(	1.108113	0.1000000	50	=	0.0000000E + 00	
dl(	1.608113	0.1000000	50	=	0.3542794	
dl(	2.108113	0.1000000	50	=	0.7085589	
dl(	2.608113	0.1000000	50	=	1.062838	
dl(	3.108113	0.1000000	50	=	1.417118	
dl(	3.608113	0.1000000	50	=	1.7711397	
dl(	4.108113	0.1000000	50	=	2.125677	
dl(	4.608113	0.1000000	50	=	2.479956	
dl(	5.108113	0.1000000	50	=	2.834235	
dl(	5.608113	0.1000000	50	=	3.188515	
dl(	6.108113	0.1000000	50	=	3.542794	
gama(beta = 0.1000000 alfa = 55) >	1.141690					
gama	beta	alfa				
dl(	1.141690	0.1000000	55	=	0.0000000E + 00	
dl(	1.641690	0.1000000	55	=	0.2890651	
dl(	2.141690	0.1000000	55	=	0.5781302	
dl(	2.641690	0.1000000	55	=	0.8671951	
dl(	3.141690	0.1000000	55	=	1.156260	
dl(	3.641690	0.1000000	55	=	1.445325	
dl(	4.141690	0.1000000	55	=	1.734390	
dl(	4.641690	0.1000000	55	=	2.023455	
dl(	5.141690	0.1000000	55	=	2.312521	
dl(	5.641690	0.1000000	55	=	2.601585	
dl(	6.141690	0.1000000	55	=	2.890651	
gama(beta = 0.1000000 alfa = 60) >	1.187500					
gama	beta	alfa				
dl(	1.187500	0.1000000	60	=	0.0000000E + 00	
dl(	1.687500	0.1000000	60	=	0.2309401	
dl(	2.187500	0.1000000	60	=	0.4618802	
dl(	2.687500	0.1000000	60	=	0.6928203	
dl(	3.187500	0.1000000	60	=	0.9237604	

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, ( $d_1 = \Delta L/R_{\epsilon_p}$ ).						
5	dl(	3.687500	0.1000000	60	=	1.154701
5	dl(	4.187500	0.1000000	60	=	1.385641
5	dl(	4.687500	0.1000000	60	=	1.616581
5	dl(	5.187500	0.1000000	60	=	1.847521
5	dl(	5.687500	0.1000000	60	=	2.078461
5	dl(	6.187500	0.1000000	60	=	2.309401
10	gama(beta = 0.1000000 alfa = 65) >	1.254602				
10	gama	beta	alfa			
10	dl(	1.254602	0.1000000	65	=	0.0000000E + 00
10	dl(	1.754602	0.1000000	65	=	0.1779849
10	dl(	2.254602	0.1000000	65	=	0.3559698
10	dl(	2.754602	0.1000000	65	=	0.5339549
15	dl(	3.254602	0.1000000	65	=	0.7119397
15	dl(	3.754602	0.1000000	65	=	0.8899247
15	dl(	4.254602	0.1000000	65	=	1.067910
15	dl(	4.754602	0.1000000	65	=	1.245895
15	dl(	5.254602	0.1000000	65	=	1.423879
15	dl(	5.754602	0.1000000	65	=	1.601864
20	dl(	6.254602	0.1000000	65	=	1.779849
20	gama(beta = 0.1000000 alfa = 70) >	1.364855				
20	gama	beta	alfa			
20	dl(	1.364855	0.1000000	70	=	0.0000000E + 00
20	dl(	1.864855	0.1000000	70	=	0.1287762
20	dl(	2.364855	0.1000000	70	=	0.2575525
20	dl(	2.864855	0.1000000	70	=	0.3863288
25	dl(	3.364855	0.1000000	70	=	0.5151050
25	dl(	3.864855	0.1000000	70	=	0.6438813
25	dl(	4.364855	0.1000000	70	=	0.7726575
25	dl(	4.864855	0.1000000	70	=	0.9014338
25	dl(	5.364855	0.1000000	70	=	1.030210
25	dl(	5.864855	0.1000000	70	=	1.158986
30	dl(	6.364855	0.1000000	70	=	1.287763
30	gama(beta = 0.1000000 alfa = 75) >	1.587469				
30	gama	beta	alfa			
30	dl(	1.587469	0.1000000	75	=	0.0000000E + 00
30	dl(	2.087469	0.1000000	75	=	0.2210816E - 02
30	dl(	2.587469	0.1000000	75	=	0.1644216
35	dl(	3.087469	0.1000000	75	=	0.2466324
35	dl(	3.587469	0.1000000	75	=	0.3288433
35	dl(	4.087469	0.1000000	75	=	0.4110541
35	dl(	4.587469	0.1000000	75	=	0.4932648
35	dl(	5.087469	0.1000000	75	=	0.5754756
35	dl(	5.587469	0.1000000	75	=	0.6576865
35	dl(	6.087469	0.1000000	75	=	0.7398973
35	dl(	6.587469	0.1000000	75	=	0.8221080
35	gama(beta = 0.1000000 alfa = 80) >	2.316863				
35	gama	beta	alfa			
35	dl(	2.316863	0.1000000	80	=	-1.0509909E - 08
35	dl(	2.816863	0.1000000	80	=	3.7392177E - 02
35	dl(	3.316863	0.1000000	80	=	7.4784376E - 02
35	dl(	3.816863	0.1000000	80	=	0.1121766
35	dl(	4.316863	0.1000000	80	=	0.1495687
35	dl(	4.816863	0.1000000	80	=	0.1869609
35	dl(	5.316863	0.1000000	80	=	0.2243531
35	dl(	5.816863	0.1000000	80	=	0.2617453
35	dl(	6.316863	0.1000000	80	=	0.2991375
35	dl(	6.816863	0.1000000	80	=	0.3365296
35	dl(	7.316863	0.1000000	80	=	0.3739218
35	gama(beta = 0.2000000 alfa = 5) >	1.001908				
35	gama	beta	alfa			
35	dl(	1.001908	0.2000000	5	=	0.0000000E + 00
35	dl(	1.501908	0.2000000	5	=	4.567655
35	dl(	2.001908	0.2000000	5	=	9.135310
35	dl(	2.501908	0.2000000	5	=	13.70297
35	dl(	3.001908	0.2000000	5	=	18.27062
35	dl(	3.501908	0.2000000	5	=	22.83828
35	dl(	4.001908	0.2000000	5	=	27.40593
35	dl(	4.501908	0.2000000	5	=	31.97359
35	dl(	5.001908	0.2000000	5	=	36.54124
35	dl(	5.501908	0.2000000	5	=	41.10890
35	dl(	6.001908	0.2000000	5	=	45.67656
35	gama(beta = 0.2000000 alfa = 10) >	1.007684				
35	gama	beta	alfa			
35	dl(	1.007684	0.2000000	10	=	0.0000000E + 00
35	dl(	1.507684	0.2000000	10	=	2.259764
35	dl(	2.007684	0.2000000	10	=	4.519529
35	dl(	2.507684	0.2000000	10	=	6.779292

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, ( $d_1 = \Delta L/R\epsilon_p$ ).					
dl(	3.007684	0.2000000	10 )=	9.039058	
dl(	3.507684	0.2000000	10 )=	11.29882	
dl(	4.007684	0.2000000	10 )=	13.55858	
dl(	4.507684	0.2000000	10 )=	15.81835	
dl(	5.007684	0.2000000	10 )=	18.07811	
dl(	5.507684	0.2000000	10 )=	20.33787	
dl(	6.007684	0.2000000	10 )=	22.59764	
gama(beta = 0.2000000 alfa = 15) >	1.017492				
gama	beta	alfa			
dl(	1.017492	0.2000000	15 )=	0.0000000E + 00	
dl(	1.517492	0.2000000	15 )=	1.479655	
dl(	2.017492	0.2000000	15 )=	2.959310	
dl(	2.517492	0.2000000	15 )=	4.438965	
dl(	3.017492	0.2000000	15 )=	5.918621	
dl(	3.517492	0.2000000	15 )=	7.398275	
dl(	4.017492	0.2000000	15 )=	8.877931	
dl(	4.517492	0.2000000	15 )=	10.35759	
dl(	5.017492	0.2000000	15 )=	11.83724	
dl(	5.517492	0.2000000	15 )=	13.31690	
dl(	6.017492	0.2000000	15 )=	14.79655	
gama(beta = 0.2000000 alfa = 20) >	1.031629				
gama	beta	alfa			
dl(	1.031629	0.2000000	20 )=	0.0000000E + 00	
dl(	1.531629	0.2000000	20 )=	1.081358	
dl(	2.031629	0.2000000	20 )=	2.162717	
dl(	2.531629	0.2000000	20 )=	3.244075	
dl(	3.031629	0.2000000	20 )=	4.325433	
dl(	3.531629	0.2000000	20 )=	5.406792	
dl(	4.031629	0.2000000	20 )=	6.488149	
dl(	4.531629	0.2000000	20 )=	7.569508	
dl(	5.031629	0.2000000	20 )=	8.650867	
dl(	5.531629	0.2000000	20 )=	9.732225	
dl(	6.031629	0.2000000	20 )=	10.81358	
gama(beta = 0.2000000 alfa = 25) >	1.050575				
gama	beta	alfa			
dl(	1.050575	0.2000000	25 )=	0.0000000E + 00	
dl(	1.550575	0.2000000	25 )=	0.8356334	
dl(	2.050575	0.2000000	25 )=	1.671267	
dl(	2.550575	0.2000000	25 )=	2.506900	
dl(	3.050575	0.2000000	25 )=	3.342533	
dl(	3.550575	0.2000000	25 )=	4.178166	
dl(	4.050575	0.2000000	25 )=	5.013800	
dl(	4.550575	0.2000000	25 )=	5.849433	
dl(	5.050575	0.2000000	25 )=	6.685066	
dl(	5.550575	0.2000000	25 )=	7.520700	
dl(	6.050575	0.2000000	25 )=	8.356333	
gama(beta = 0.2000000 alfa = 30) >	1.075072				
gama	beta	alfa			
dl(	1.075072	0.2000000	30 )=	-1.0323828E - 07	
dl(	1.575072	0.2000000	30 )=	0.6660254	
dl(	2.075072	0.2000000	30 )=	1.332051	
dl(	2.575072	0.2000000	30 )=	1.998076	
dl(	3.075072	0.2000000	30 )=	2.664102	
dl(	3.575072	0.2000000	30 )=	3.330127	
dl(	4.075072	0.2000000	30 )=	3.996153	
dl(	4.575072	0.2000000	30 )=	4.662178	
dl(	5.075072	0.2000000	30 )=	5.328203	
dl(	5.575072	0.2000000	30 )=	5.994229	
dl(	6.075072	0.2000000	30 )=	6.660254	
gama(beta = 0.2000000 alfa = 35) >	1.106271				
gama	beta	alfa			
dl(	1.106271	0.2000000	35 )=	0.0000000E + 00	
dl(	1.606271	0.2000000	35 )=	0.5397293	
dl(	2.106271	0.2000000	35 )=	1.079459	
dl(	2.606271	0.2000000	35 )=	1.619188	
dl(	3.106271	0.2000000	35 )=	2.158918	
dl(	3.606271	0.2000000	35 )=	2.698647	
dl(	4.106271	0.2000000	35 )=	3.238376	
dl(	4.606271	0.2000000	35 )=	3.778105	
dl(	5.106271	0.2000000	35 )=	4.317834	
dl(	5.606271	0.2000000	35 )=	4.857564	
dl(	6.106271	0.2000000	35 )=	5.397293	
gama(beta = 0.2000000 alfa = 40) >	1.145987				
gama	beta	alfa			
dl(	1.145987	0.2000000	40 )=	0.0000000E + 00	
dl(	1.645987	0.2000000	40 )=	0.4403043	
dl(	2.145987	0.2000000	40 )=	0.8806087	

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, ( $d_1 = \Delta L/R\epsilon_p$ ).					
5	dl(	2.645987	0.2000000	40 )=	1.320913
	dl(	3.145987	0.2000000	40 )=	1.761218
	dl(	3.645987	0.2000000	40 )=	2.201522
	dl(	4.145987	0.2000000	40 )=	2.641827
	dl(	4.645987	0.2000000	40 )=	3.082131
	dl(	5.145987	0.2000000	40 )=	3.522435
10	dl(	5.645987	0.2000000	40 )=	3.962740
	dl(	6.145987	0.2000000	40 )=	4.403044
	gama(beta = 0.2000000 alfa = 45) >	1.197197			
	gama	beta	alfa		
	dl(	1.197197	0.2000000	45 )=	0.0000000E + 00
	dl(	1.697197	0.2000000	45 )=	0.3585786
15	dl(	2.197197	0.2000000	45 )=	0.7171574
	dl(	2.697197	0.2000000	45 )=	1.075736
	dl(	3.197197	0.2000000	45 )=	1.434315
	dl(	3.697197	0.2000000	45 )=	1.792893
	dl(	4.197197	0.2000000	45 )=	2.151472
	dl(	4.697197	0.2000000	45 )=	2.510051
20	dl(	5.197197	0.2000000	45 )=	2.868629
	dl(	5.697197	0.2000000	45 )=	3.227208
	dl(	6.197197	0.2000000	45 )=	3.585786
	gama(beta = 0.2000000 alfa = 50) >	1.265059			
	gama	beta	alfa		
	dl(	1.265059	0.2000000	50 )=	0.0000000E + 00
	dl(	1.765059	0.2000000	50 )=	0.2890092
25	dl(	2.265059	0.2000000	50 )=	0.5780182
	dl(	2.765059	0.2000000	50 )=	0.8670272
	dl(	3.265059	0.2000000	50 )=	1.156036
	dl(	3.765059	0.2000000	50 )=	1.445045
	dl(	4.265059	0.2000000	50 )=	1.734055
	dl(	4.765059	0.2000000	50 )=	2.023064
30	dl(	5.265059	0.2000000	50 )=	2.312073
	dl(	5.765059	0.2000000	50 )=	2.601082
	dl(	6.265059	0.2000000	50 )=	2.890091
	gama(beta = 0.2000000 alfa = 55) >	1.359236			
	gama	beta	alfa		
	dl(	1.359236	0.2000000	55 )=	0.0000000E + 00
	dl(	1.859236	0.2000000	55 )=	0.2280263
35	dl(	2.359236	0.2000000	55 )=	0.4560528
	dl(	2.859236	0.2000000	55 )=	0.6840791
	dl(	3.359236	0.2000000	55 )=	0.9121054
	dl(	3.859236	0.2000000	55 )=	1.140132
	dl(	4.359236	0.2000000	55 )=	1.368158
40	dl(	4.859236	0.2000000	55 )=	1.596184
	dl(	5.359236	0.2000000	55 )=	1.824211
	dl(	5.859236	0.2000000	55 )=	2.052237
	dl(	6.359236	0.2000000	55 )=	2.280263
	gama(beta = 0.2000000 alfa = 60) >	1.500000			
	gama	beta	alfa		
45	dl(	1.500000	0.2000000	60 )=	0.0000000E + 00
	dl(	2.000000	0.2000000	60 )=	0.1732051
	dl(	2.500000	0.2000000	60 )=	0.3464102
	dl(	3.000000	0.2000000	60 )=	0.5196153
	dl(	3.500000	0.2000000	60 )=	0.6928202
	dl(	4.000000	0.2000000	60 )=	0.8660252
	dl(	4.500000	0.2000000	60 )=	1.039230
50	dl(	5.000000	0.2000000	60 )=	1.212435
	dl(	5.500000	0.2000000	60 )=	1.385640
	dl(	6.000000	0.2000000	60 )=	1.558846
	dl(	6.500000	0.2000000	60 )=	1.732051
	gama(beta = 0.2000000 alfa = 65) >	1.737939			
	gama	beta	alfa		
55	dl(	1.000848	0.2000000	65 )=	0.0000000E + 00
	dl(	2.237939	0.2000000	65 )=	0.1228161
	dl(	2.737939	0.2000000	65 )=	0.2456321
	dl(	3.237939	0.2000000	65 )=	0.3684481
	dl(	3.737939	0.2000000	65 )=	0.4912642
	dl(	4.237939	0.2000000	65 )=	0.6140803
	dl(	4.737939	0.2000000	65 )=	0.7368963
60	dl(	5.237939	0.2000000	65 )=	0.8597122
	dl(	5.737939	0.2000000	65 )=	0.9825283
	dl(	6.237939	0.2000000	65 )=	1.105344
	dl(	6.737939	0.2000000	65 )=	1.228161
	gama(beta = 0.2000000 alfa = 70) >	2.243517			
	gama	beta	alfa		
65	dl(	2.243517	0.2000000	70 )=	0.0000000E + 00
	dl(	2.743517	0.2000000	70 )=	7.5567380E - 02

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, ( $d_1 = \Delta L/R_{\epsilon_p}$ ).						
dl(	3.243517	0.2000000	70	=	0.1511347	
dl(	3.743517	0.2000000	70	=	0.2267021	
dl(	4.243517	0.2000000	70	=	0.3022694	
dl(	4.743517	0.2000000	70	=	0.3778368	
dl(	5.243517	0.2000000	70	=	0.4534041	
dl(	5.743517	0.2000000	70	=	0.5289715	
dl(	6.243517	0.2000000	70	=	0.6045388	
dl(	6.743517	0.2000000	70	=	0.6801062	
dl(	7.243517	0.2000000	70	=	0.7556735	
gama(beta = 0.2000000 alfa = 75) >	4.172484					
gama	beta	alfa				
dl(	4.172484	0.2000000	75	=	0.0000000E + 00	
dl(	4.672484	0.2000000	75	=	3.0446989E - 02	
dl(	5.172484	0.2000000	75	=	6.0893979E - 02	
dl(	5.672484	0.2000000	75	=	9.1340967E - 02	
dl(	6.172484	0.2000000	75	=	0.1217880	
dl(	6.672484	0.2000000	75	=	0.1522349	
dl(	7.172484	0.2000000	75	=	0.1826819	
dl(	7.672484	0.2000000	75	=	0.2131289	
dl(	8.172484	0.2000000	75	=	0.2435759	
dl(	8.672484	0.2000000	75	=	0.2740229	
dl(	9.172484	0.2000000	75	=	0.3044699	
gama(beta = 0.3000000 alfa = 5) >	1.003273					
gama	beta	alfa				
dl(	1.003273	0.3000000	5	=	0.0000000E + 00	
dl(	1.503273	0.3000000	5	=	3.993970	
dl(	2.003273	0.3000000	5	=	7.987939	
dl(	2.503273	0.3000000	5	=	11.98191	
dl(	3.003273	0.3000000	5	=	15.97588	
dl(	3.503273	0.3000000	5	=	19.96985	
dl(	4.003273	0.3000000	5	=	23.96382	
dl(	4.503273	0.3000000	5	=	27.95779	
dl(	5.003273	0.3000000	5	=	31.95176	
dl(	5.503273	0.3000000	5	=	35.94573	
dl(	6.003273	0.3000000	5	=	39.93970	
gama(beta = 0.3000000 alfa = 10) >	1.013210					
gama	beta	alfa				
dl(	1.013210	0.3000000	10	=	0.0000000E + 00	
dl(	1.513210	0.3000000	10	=	1.971826	
dl(	2.013210	0.3000000	10	=	3.943652	
dl(	2.513210	0.3000000	10	=	5.915477	
dl(	3.013210	0.3000000	10	=	7.887302	
dl(	3.513210	0.3000000	10	=	9.859128	
dl(	4.013210	0.3000000	10	=	11.83095	
dl(	4.513210	0.3000000	10	=	13.80278	
dl(	5.013210	0.3000000	10	=	15.77460	
dl(	5.513210	0.3000000	10	=	17.74643	
dl(	6.013210	0.3000000	10	=	19.71825	
gama(beta = 0.3000000 alfa = 15) >	1.030178					
gama	beta	alfa				
dl(	1.030178	0.3000000	15	=	0.0000000E + 00	
dl(	1.530178	0.3000000	15	=	1.286470	
dl(	2.030178	0.3000000	15	=	2.572940	
dl(	2.530178	0.3000000	15	=	3.859410	
dl(	3.030178	0.3000000	15	=	5.145880	
dl(	3.530178	0.3000000	15	=	6.432350	
dl(	4.030178	0.3000000	15	=	7.718821	
dl(	4.530178	0.3000000	15	=	9.005290	
dl(	5.030178	0.3000000	15	=	10.29176	
dl(	5.530178	0.3000000	15	=	11.57823	
dl(	6.030178	0.3000000	15	=	12.86470	
gama(beta = 0.3000000 alfa = 20) >	1.054860					
gama	beta	alfa				
dl(	1.054860	0.3000000	20	=	0.0000000E + 00	
dl(	1.554860	0.3000000	20	=	0.9351683	
dl(	2.054860	0.3000000	20	=	1.870337	
dl(	2.554860	0.3000000	20	=	2.805505	
dl(	3.054860	0.3000000	20	=	3.740673	
dl(	3.554860	0.3000000	20	=	4.675841	
dl(	4.054860	0.3000000	20	=	5.611008	
dl(	4.554860	0.3000000	20	=	6.546177	
dl(	5.054860	0.3000000	20	=	7.481345	
dl(	5.554860	0.3000000	20	=	8.416512	
dl(	6.054860	0.3000000	20	=	9.351681	
gama(beta = 0.3000000 alfa = 25) >	1.088374					
gama	beta	alfa				
dl(	1.088374	0.3000000	25	=	0.0000000E + 00	

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, ( $d_1 = \Delta L/R_{\epsilon_p}$ ).						
5	dl(	1.588374	0.3000000	25	=	0.7173234
	dl(	2.088374	0.3000000	25	=	1.434647
	dl(	2.588374	0.3000000	25	=	2.151970
	dl(	3.088374	0.3000000	25	=	2.869293
	dl(	3.588374	0.3000000	25	=	3.586617
	dl(	4.088374	0.3000000	25	=	4.303940
10	dl(	4.588374	0.3000000	25	=	5.021263
	dl(	5.088374	0.3000000	25	=	5.738586
	dl(	5.588374	0.3000000	25	=	6.455910
	dl(	6.088374	0.3000000	25	=	7.173233
	gama(beta = 0.3000000 alfa = 30) >	1.132503				
	gama	beta	alfa			
15	dl(	1.132503	0.3000000	30	=	0.0000000E + 00
	dl(	1.632503	0.3000000	30	=	0.5660253
	dl(	2.132503	0.3000000	30	=	1.132051
	dl(	2.632503	0.3000000	30	=	1.698076
	dl(	3.132503	0.3000000	30	=	2.264102
20	dl(	4.132503	0.3000000	30	=	3.396153
	dl(	4.632503	0.3000000	30	=	3.962178
	dl(	5.132503	0.3000000	30	=	4.528203
	dl(	5.632503	0.3000000	30	=	5.094229
	dl(	6.132503	0.3000000	30	=	5.660254
	gama(beta = 0.3000000 alfa = 35) >	1.190112				
	gama	beta	alfa			
25	dl(	1.190112	0.3000000	35	=	0.0000000E + 00
	dl(	1.690112	0.3000000	35	=	0.4525571
	dl(	2.190112	0.3000000	35	=	0.9051141
	dl(	2.690112	0.3000000	35	=	1.357671
	dl(	3.190112	0.3000000	35	=	1.810228
	dl(	3.690112	0.3000000	35	=	2.262785
30	dl(	4.190112	0.3000000	35	=	2.715343
	dl(	4.690112	0.3000000	35	=	3.167900
	dl(	5.190112	0.3000000	35	=	3.620456
	dl(	5.690112	0.3000000	35	=	4.073013
	dl(	6.190112	0.3000000	35	=	4.525570
	gama(beta = 0.3000000 alfa = 40) >	1.265968				
35	dl(	1.265968	0.3000000	40	=	0.0000000E + 00
	dl(	1.765968	0.3000000	40	=	0.3625183
	dl(	2.265968	0.3000000	40	=	0.7250366
	dl(	2.765968	0.3000000	40	=	1.087555
40	dl(	3.265968	0.3000000	40	=	1.450073
	dl(	3.765968	0.3000000	40	=	1.812591
	dl(	4.265968	0.3000000	40	=	2.175110
	dl(	4.765968	0.3000000	40	=	2.537628
	dl(	5.265968	0.3000000	40	=	2.900146
	dl(	5.765968	0.3000000	40	=	3.262665
	dl(	6.265968	0.3000000	40	=	3.625183
	gama(beta = 0.3000000 alfa = 45) >	1.368454				
45	dl(	1.368454	0.3000000	45	=	0.0000000E + 00
	dl(	1.868454	0.3000000	45	=	0.2878680
	dl(	2.368454	0.3000000	45	=	0.5757360
	dl(	2.868454	0.3000000	45	=	0.8636041
	dl(	3.368454	0.3000000	45	=	1.151472
	dl(	3.868454	0.3000000	45	=	1.439340
	dl(	4.368454	0.3000000	45	=	1.727208
	dl(	4.868454	0.3000000	45	=	2.015076
	dl(	5.368454	0.3000000	45	=	2.302944
	dl(	5.868454	0.3000000	45	=	2.590812
	dl(	6.368454	0.3000000	45	=	2.878680
55	gama(beta = 0.3000000 alfa = 50) >	1.513575				
	gama	beta	alfa			
	dl(	1.513575	0.3000000	50	=	0.0000000E + 00
	dl(	2.013575	0.3000000	50	=	0.2237388
	dl(	2.513575	0.3000000	50	=	0.4474775
	dl(	3.013575	0.3000000	50	=	0.6712162
	dl(	3.513575	0.3000000	50	=	0.8949549
60	dl(	4.013576	0.3000000	50	=	1.118694
	dl(	4.513576	0.3000000	50	=	1.342432
	dl(	5.013576	0.3000000	50	=	1.566171
	dl(	5.513576	0.3000000	50	=	1.789910
	dl(	6.013576	0.3000000	50	=	2.013649
	dl(	6.513576	0.3000000	50	=	2.237387
65	gama(beta = 0.3000000 alfa = 55) >	1.735820				
	gama	beta	alfa			

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, ( $d_1 = \Delta L/R_{\epsilon_p}$ ).						
dl(	1.735820	0.3000000	55	=	0.0000000E + 00	
dl(	2.235820	0.3000000	55	=	0.1669876	
dl(	2.735820	0.3000000	55	=	0.3339752	
dl(	3.235820	0.3000000	55	=	0.5009628	
dl(	3.735820	0.3000000	55	=	0.6679505	
dl(	4.235820	0.3000000	55	=	0.8349380	
dl(	4.735820	0.3000000	55	=	1.001926	
dl(	5.235820	0.3000000	55	=	1.168913	
dl(	5.735820	0.3000000	55	=	1.335901	
dl(	6.235820	0.3000000	55	=	1.502888	
dl(	6.735820	0.3000000	55	=	1.669876	
gama(beta = 0.3000000 alfa = 60) >	2.125000					
gama	beta	alfa				
dl(	2.125000	0.3000000	60	=	0.0000000E + 00	
dl(	2.625000	0.3000000	60	=	0.1154701	
dl(	3.125000	0.3000000	60	=	0.2309401	
dl(	3.625000	0.3000000	60	=	0.3464102	
dl(	4.125000	0.3000000	60	=	0.4618802	
dl(	4.625000	0.3000000	60	=	0.5773503	
dl(	5.125000	0.3000000	60	=	0.6928203	
dl(	5.625000	0.3000000	60	=	0.8082904	
dl(	6.125000	0.3000000	60	=	0.9237605	
dl(	6.625000	0.3000000	60	=	1.039231	
dl(	7.125000	0.3000000	60	=	1.154701	
gama(beta = 0.3000000 alfa = 65) >	3.009636					
gama	beta	alfa				
dl(	3.009636	0.3000000	65	=	0.0000000E + 00	
dl(	3.509636	0.3000000	65	=	6.7647174E - 02	
dl(	4.009636	0.3000000	65	=	0.1352943	
dl(	4.509636	0.3000000	65	=	0.2029415	
dl(	5.009636	0.3000000	65	=	0.2705886	
dl(	5.509636	0.3000000	65	=	0.3382358	
dl(	6.009636	0.3000000	65	=	0.4058830	
dl(	6.509636	0.3000000	65	=	0.4735300	
dl(	7.009636	0.3000000	65	=	0.5411772	
dl(	7.509636	0.3000000	65	=	0.6088244	
dl(	8.009637	0.3000000	65	=	0.6764715	
gama(beta = 0.3000000 alfa = 70) >	7.304273					
gama	beta	alfa				
dl(	7.304273	0.3000000	70	=	0.0000000E + 00	
dl(	7.804273	0.3000000	70	=	2.2358468E - 02	
dl(	8.304274	0.3000000	70	=	4.4716977E - 02	
dl(	8.804274	0.3000000	70	=	6.7075446E - 02	
dl(	9.304274	0.3000000	70	=	8.9433916E - 02	
dl(	9.804274	0.3000000	70	=	0.1117924	
dl(	10.30427	0.3000000	70	=	0.1341508	
dl(	10.80427	0.3000000	70	=	0.1565093	
dl(	11.30427	0.3000000	70	=	0.1788678	
dl(	11.80427	0.3000000	70	=	0.2012262	
dl(	12.30427	0.3000000	70	=	0.2235847	
gama(beta = 0.4000000 alfa = 5) >	1.005096					
gama	beta	alfa				
dl(	1.005096	0.4000000	5	=	0.0000000E + 00	
dl(	1.505096	0.4000000	5	=	3.420284	
dl(	2.005096	0.4000000	5	=	6.840568	
dl(	2.505096	0.4000000	5	=	10.26085	
dl(	3.005096	0.4000000	5	=	13.68113	
dl(	3.505096	0.4000000	5	=	17.10142	
dl(	4.005096	0.4000000	5	=	20.52170	
dl(	4.505096	0.4000000	5	=	23.94199	
dl(	5.005096	0.4000000	5	=	27.36227	
dl(	5.505096	0.4000000	5	=	30.78255	
dl(	6.005096	0.4000000	5	=	34.20284	
gama(beta = 0.4000000 alfa = 10) >	1.020625					
gama	beta	alfa				
dl(	1.020625	0.4000000	10	=	0.0000000E + 00	
dl(	1.520625	0.4000000	10	=	1.683887	
dl(	2.020625	0.4000000	10	=	3.367775	
dl(	2.520625	0.4000000	10	=	5.051661	
dl(	3.020625	0.4000000	10	=	6.735548	
dl(	3.520625	0.4000000	10	=	8.419435	
dl(	4.020625	0.4000000	10	=	10.10332	
dl(	4.520625	0.4000000	10	=	11.78721	
dl(	5.020625	0.4000000	10	=	13.47109	
dl(	5.520625	0.4000000	10	=	15.15498	
dl(	6.020625	0.4000000	10	=	16.83887	
gama(beta = 0.4000000 alfa = 15) >	1.047347					

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, ( $d_1 = \Delta L/R_{\epsilon_p}$ ).						
5	gama	beta	alfa			
dl(	1.047347	0.4000000	15	=	0.0000000E + 00	
dl(	1.547347	0.4000000	15	=	1.093285	
dl(	2.047347	0.4000000	15	=	2.186569	
dl(	2.547347	0.4000000	15	=	3.279854	
dl(	3.047347	0.4000000	15	=	4.373139	
10	dl(	3.547347	0.4000000	15	=	5.466424
dl(	4.047347	0.4000000	15	=	6.559709	
dl(	4.547347	0.4000000	15	=	7.652993	
dl(	5.047347	0.4000000	15	=	8.746278	
dl(	5.547347	0.4000000	15	=	9.839563	
dl(	6.047347	0.4000000	15	=	10.93285	
15	gama(beta = 0.4000000 alfa = 20) >	1.086700				
gama	beta	alfa				
dl(	1.086700	0.4000000	20	=	0.0000000E + 00	
dl(	1.586700	0.4000000	20	=	0.7889779	
dl(	2.086700	0.4000000	20	=	1.577956	
dl(	2.586700	0.4000000	20	=	2.366934	
20	dl(	3.086700	0.4000000	20	=	3.155912
dl(	3.586700	0.4000000	20	=	3.944890	
dl(	4.086699	0.4000000	20	=	4.733867	
dl(	4.586699	0.4000000	20	=	5.522845	
dl(	5.086699	0.4000000	20	=	6.311823	
dl(	5.586699	0.4000000	20	=	7.100801	
dl(	6.086699	0.4000000	20	=	7.889779	
25	gama(beta = 0.4000000 alfa = 25) >	1.141105				
gama	beta	alfa				
dl(	1.141105	0.4000000	25	=	0.0000000E + 00	
dl(	1.641105	0.4000000	25	=	0.5990134	
dl(	2.141105	0.4000000	25	=	1.198027	
dl(	2.641105	0.4000000	25	=	1.797040	
30	dl(	3.141105	0.4000000	25	=	2.396053
dl(	3.641105	0.4000000	25	=	2.995066	
dl(	4.141105	0.4000000	25	=	3.594079	
dl(	4.641105	0.4000000	25	=	4.193092	
dl(	5.141105	0.4000000	25	=	4.792106	
dl(	5.641105	0.4000000	25	=	5.391119	
dl(	6.141105	0.4000000	25	=	5.990132	
35	gama(beta = 0.4000000 alfa = 30) >	1.214581				
gama	beta	alfa				
dl(	1.214581	0.4000000	30	=	0.0000000E + 00	
dl(	1.714581	0.4000000	30	=	0.4660254	
dl(	2.214581	0.4000000	30	=	0.9320508	
40	dl(	2.714581	0.4000000	30	=	1.398076
dl(	3.214581	0.4000000	30	=	1.864102	
dl(	3.714581	0.4000000	30	=	2.330127	
dl(	4.214581	0.4000000	30	=	2.796153	
dl(	4.714581	0.4000000	30	=	3.262178	
dl(	5.214581	0.4000000	30	=	3.728203	
dl(	5.714581	0.4000000	30	=	4.194229	
45	dl(	6.214581	0.4000000	30	=	4.660254
gama(beta = 0.4000000 alfa = 35) >	1.313958					
gama	beta	alfa				
dl(	1.313958	0.4000000	35	=	0.0000000E + 00	
dl(	1.813958	0.4000000	35	=	0.3653848	
dl(	2.313958	0.4000000	35	=	0.7307695	
50	dl(	2.813958	0.4000000	35	=	1.096154
dl(	3.313958	0.4000000	35	=	1.461539	
dl(	3.813958	0.4000000	35	=	1.826923	
dl(	4.313958	0.4000000	35	=	2.192308	
dl(	4.813958	0.4000000	35	=	2.557693	
dl(	5.313958	0.4000000	35	=	2.923077	
55	dl(	5.813958	0.4000000	35	=	3.288462
dl(	6.313958	0.4000000	35	=	3.653847	
gama(beta = 0.4000000 alfa = 40) >	1.451504					
gama	beta	alfa				
dl(	1.451504	0.4000000	40	=	0.0000000E + 00	
dl(	1.951504	0.4000000	40	=	0.2847320	
dl(	2.451504	0.4000000	40	=	0.5694641	
60	dl(	2.951504	0.4000000	40	=	0.8541961
dl(	3.451504	0.4000000	40	=	1.138928	
dl(	3.951504	0.4000000	40	=	1.423660	
dl(	4.451504	0.4000000	40	=	1.708392	
dl(	4.951504	0.4000000	40	=	1.993124	
65	dl(	5.451504	0.4000000	40	=	2.277856
dl(	5.951504	0.4000000	40	=	2.562588	
gama(beta = 0.4000000 alfa = 40) >	2.847321					

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, ( $d_1 = \Delta L/R_{\epsilon_p}$ ).			
gama(beta = 0.4000000	alfa = 45) >	1.651239	
gama	beta	alfa	
dl( 1.651239	0.4000000	45 )=	0.0000000E + 00
dl( 2.151239	0.4000000	45 )=	0.2171572
dl( 2.651239	0.4000000	45 )=	0.4343146
dl( 3.151239	0.4000000	45 )=	0.6514719
dl( 3.651239	0.4000000	45 )=	0.8686291
dl( 4.151239	0.4000000	45 )=	1.085786
dl( 4.651239	0.4000000	45 )=	1.302943
dl( 5.151239	0.4000000	45 )=	1.520101
dl( 5.651239	0.4000000	45 )=	1.737258
dl( 6.151239	0.4000000	45 )=	1.954415
dl( 6.651239	0.4000000	45 )=	2.171573
gama(beta = 0.4000000	alfa = 50) >	1.966811	
gama	beta	alfa	
dl( 1.966811	0.4000000	50 )=	0.0000000E + 00
dl( 2.466811	0.4000000	50 )=	0.1584684
dl( 2.966811	0.4000000	50 )=	0.3169367
dl( 3.466811	0.4000000	50 )=	0.4754050
dl( 3.966811	0.4000000	50 )=	0.6338733
dl( 4.466811	0.4000000	50 )=	0.7923417
dl( 4.966811	0.4000000	50 )=	0.9508100
dl( 5.466811	0.4000000	50 )=	1.109279
dl( 5.966811	0.4000000	50 )=	1.267747
dl( 6.466811	0.4000000	50 )=	1.426215
dl( 6.966811	0.4000000	50 )=	1.584683
gama(beta = 0.4000000	alfa = 55) >	2.546316	
gama	beta	alfa	
dl( 2.546316	0.4000000	55 )=	0.0000000E + 00
dl( 3.046316	0.4000000	55 )=	0.1059489
dl( 3.546316	0.4000000	55 )=	0.2118977
dl( 4.046316	0.4000000	55 )=	0.3178467
dl( 4.546316	0.4000000	55 )=	0.4237956
dl( 5.046316	0.4000000	55 )=	0.5297443
dl( 5.546316	0.4000000	55 )=	0.6356933
dl( 6.046316	0.4000000	55 )=	0.7416422
dl( 6.546316	0.4000000	55 )=	0.8475911
dl( 7.046316	0.4000000	55 )=	0.9535400
dl( 7.546316	0.4000000	55 )=	1.059489
gama(beta = 0.4000000	alfa = 60) >	4.000001	
gama	beta	alfa	
dl( 1.000848	0.4000000	5 )=	0.0000000E + 00
dl( 4.500001	0.4000000	60 )=	5.7735037E - 02
dl( 5.000001	0.4000000	60 )=	0.1154700
dl( 5.500001	0.4000000	60 )=	0.1732050
dl( 6.000001	0.4000000	60 )=	0.2309400
dl( 6.500001	0.4000000	60 )=	0.2886750
dl( 7.000001	0.4000000	60 )=	0.3464100
dl( 7.500001	0.4000000	60 )=	0.4041451
dl( 8.000002	0.4000000	60 )=	0.4618801
dl( 8.500002	0.4000000	60 )=	0.5196151
dl( 9.000002	0.4000000	60 )=	0.5773501
gama(beta = 0.4000000	alfa = 65) >	15.52622	
gama	beta	alfa	
dl( 15.52622	0.4000000	65 )=	0.0000000E + 00
dl( 16.02622	0.4000000	65 )=	1.2478273E - 02
dl( 16.52622	0.4000000	65 )=	2.4956491E - 02
dl( 17.02622	0.4000000	65 )=	3.7343746E - 02
dl( 17.52622	0.4000000	65 )=	4.9912982E - 02
dl( 18.02622	0.4000000	65 )=	6.2391199E - 02
dl( 18.52622	0.4000000	65 )=	7.4869417E - 02
dl( 19.02622	0.4000000	65 )=	8.7347694E - 02
dl( 19.52622	0.4000000	65 )=	9.9825911E - 02
dl( 20.02622	0.4000000	65 )=	0.1123041
dl( 20.52622	0.4000000	65 )=	0.1247824
gama(beta = 0.5000000	alfa = 5) >	1.007654	
gama	beta	alfa	
dl( 1.007654	0.5000000	5 )=	0.0000000E + 00
dl( 1.507654	0.5000000	5 )=	2.846598
dl( 2.007654	0.5000000	5 )=	5.693197
dl( 2.507654	0.5000000	5 )=	8.539796
dl( 3.007654	0.5000000	5 )=	11.38639
dl( 3.507654	0.5000000	5 )=	14.23299
dl( 4.007654	0.5000000	5 )=	17.07959
dl( 4.507654	0.5000000	5 )=	19.92619
dl( 5.007654	0.5000000	5 )=	22.77279

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, ( $d_1 = \Delta L/R_{\epsilon_p}$ ).			
5 dl( 5.507654	0.5000000	5 )=	25.61938
dl( 6.007654	0.5000000	5 )=	28.46598
gama(beta = 0.5000000	alfa = 10) >	1.031099	
gama	beta	alfa	
dl( 1.031099	0.5000000	5 )=	0.0000000E + 00
dl( 1.531099	0.5000000	10 )=	1.395948
10 dl( 2.031099	0.5000000	10 )=	2.791897
dl( 2.531099	0.5000000	10 )=	4.187845
dl( 3.031099	0.5000000	10 )=	5.583793
dl( 3.531099	0.5000000	10 )=	6.979742
dl( 4.031099	0.5000000	10 )=	8.375691
dl( 4.531099	0.5000000	10 )=	9.771640
15 dl( 5.031099	0.5000000	10 )=	11.16759
dl( 5.531099	0.5000000	10 )=	12.56354
dl( 6.031099	0.5000000	10 )=	13.95948
gama(beta = 0.5000000	alfa = 15) >	1.071886	
gama	beta	alfa	
dl( 1.071886	0.5000000	15 )=	0.0000000E + 00
dl( 1.571886	0.5000000	15 )=	0.9000998
20 dl( 2.071886	0.5000000	15 )=	1.800200
dl( 2.571886	0.5000000	15 )=	2.700299
dl( 3.071886	0.5000000	15 )=	3.600399
dl( 3.571886	0.5000000	15 )=	4.500498
dl( 4.071886	0.5000000	15 )=	5.400597
dl( 4.571886	0.5000000	15 )=	6.300696
25 dl( 5.071886	0.5000000	15 )=	7.200796
dl( 5.571886	0.5000000	15 )=	8.100896
dl( 6.071886	0.5000000	15 )=	9.000996
gama(beta = 0.5000000	alfa = 20) >	1.133022	
gama	beta	alfa	
dl( 1.133022	0.5000000	20 )=	0.0000000E + 00
30 dl( 1.633022	0.5000000	20 )=	0.6427878
dl( 2.133022	0.5000000	20 )=	1.285576
dl( 2.633022	0.5000000	20 )=	1.928363
dl( 3.133022	0.5000000	20 )=	2.571151
dl( 3.633022	0.5000000	20 )=	3.213938
dl( 4.133022	0.5000000	20 )=	3.856726
35 dl( 4.633022	0.5000000	20 )=	4.499513
dl( 5.133022	0.5000000	20 )=	5.142301
dl( 5.633022	0.5000000	20 )=	5.785089
dl( 6.133022	0.5000000	20 )=	6.427876
gama(beta = 0.5000000	alfa = 25) >	1.219792	
gama	beta	alfa	
40 dl( 1.219792	0.5000000	25 )=	0.0000000E + 00
dl( 1.719792	0.5000000	25 )=	0.4807031
dl( 2.219792	0.5000000	25 )=	0.9614062
dl( 2.719792	0.5000000	25 )=	1.442109
dl( 3.219792	0.5000000	25 )=	1.922812
dl( 3.719792	0.5000000	25 )=	2.403515
45 dl( 4.219792	0.5000000	25 )=	2.884219
dl( 4.719792	0.5000000	25 )=	3.364922
dl( 5.219792	0.5000000	25 )=	3.845624
dl( 5.719792	0.5000000	25 )=	4.326327
dl( 6.219792	0.5000000	25 )=	4.807031
gama(beta = 0.5000000	alfa = 30) >	1.341506	
gama	beta	alfa	
50 dl( 1.341506	0.5000000	30 )=	0.0000000E + 00
dl( 1.841506	0.5000000	30 )=	0.3660255
dl( 2.341506	0.5000000	30 )=	0.7320511
dl( 2.841506	0.5000000	30 )=	1.098076
dl( 3.341506	0.5000000	30 )=	1.464102
dl( 3.841506	0.5000000	30 )=	1.830127
55 dl( 4.341506	0.5000000	30 )=	2.196153
dl( 4.841506	0.5000000	30 )=	2.562178
dl( 5.341506	0.5000000	30 )=	2.928203
dl( 5.841506	0.5000000	30 )=	3.294229
dl( 6.341506	0.5000000	30 )=	3.660254
gama(beta = 0.5000000	alfa = 35) >	1.515412	
gama	beta	alfa	
60 dl( 1.515412	0.5000000	35 )=	0.0000000E + 00
dl( 2.015413	0.5000000	35 )=	0.2782125
dl( 2.515413	0.5000000	35 )=	0.5564247
dl( 3.015413	0.5000000	35 )=	0.8346372
dl( 3.515413	0.5000000	35 )=	1.112849
65 dl( 4.015412	0.5000000	35 )=	1.391062
dl( 4.515412	0.5000000	35 )=	1.669274
dl( 5.015412	0.5000000	35 )=	1.947486

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, ( $d_1 = \Delta L/R_{\epsilon_p}$ ).					
dl(	5.515412	0.5000000	35	=	2.225699
dl(	6.015412	0.5000000	35	=	2.503911
dl(	6.515412	0.5000000	35	=	2.782123
gama(beta = 0.5000000 alfa = 40) >	1.776517				
gama	beta	alfa			
dl(	1.776517	0.5000000	40	=	0.0000000E + 00
dl(	2.276517	0.5000000	40	=	0.2069459
dl(	2.776517	0.5000000	40	=	0.4138919
dl(	3.276517	0.5000000	40	=	0.6208376
dl(	3.776517	0.5000000	40	=	0.8277834
dl(	4.276517	0.5000000	40	=	1.034729
dl(	4.776517	0.5000000	40	=	1.241675
dl(	5.276517	0.5000000	40	=	1.448621
dl(	5.776517	0.5000000	40	=	1.655567
dl(	6.276517	0.5000000	40	=	1.8622513
dl(	6.776517	0.5000000	40	=	2.069459
gama(beta = 0.5000000 alfa = 45) >	2.207107				
gama	beta	alfa			
dl(	2.207107	0.5000000	45	=	0.0000000E + 00
dl(	2.707107	0.5000000	45	=	0.1464467
dl(	3.207107	0.5000000	45	=	0.2928933
dl(	3.707107	0.5000000	45	=	0.4393399
dl(	4.207107	0.5000000	45	=	0.5857866
dl(	4.707107	0.5000000	45	=	0.7322332
dl(	5.207107	0.5000000	45	=	0.8786799
dl(	5.707107	0.5000000	45	=	1.025126
dl(	6.207107	0.5000000	45	=	1.171573
dl(	6.707107	0.5000000	45	=	1.318020
dl(	7.207107	0.5000000	45	=	1.464466
gama(beta = 0.5000000 alfa = 50) >	3.054885				
gama	beta	alfa			
dl(	3.054885	0.5000000	50	=	0.0000000E + 00
dl(	3.554885	0.5000000	50	=	9.3198024E - 02
dl(	4.054885	0.5000000	50	=	0.1863960
dl(	4.554885	0.5000000	50	=	0.2795941
dl(	5.054885	0.5000000	50	=	0.3727920
dl(	5.554885	0.5000000	50	=	0.4659900
dl(	6.054885	0.5000000	50	=	0.5591879
dl(	6.554885	0.5000000	50	=	0.6523860
dl(	7.054885	0.5000000	50	=	0.7455839
dl(	7.554885	0.5000000	50	=	0.8387819
dl(	8.054885	0.5000000	50	=	0.9319797
gama(beta = 0.5000000 alfa = 55) >	5.559950				
gama	beta	alfa			
dl(	5.559950	0.5000000	55	=	0.0000000E + 00
dl(	6.059950	0.5000000	55	=	4.4910204E - 02
dl(	6.559950	0.5000000	55	=	8.9820325E - 02
dl(	7.059950	0.5000000	55	=	0.1347304
dl(	7.559950	0.5000000	55	=	0.1796406
dl(	8.059951	0.5000000	55	=	0.2245508
dl(	8.559951	0.5000000	55	=	0.2694609
dl(	9.059951	0.5000000	55	=	0.3143710
dl(	9.559951	0.5000000	55	=	0.35992812
dl(	10.05995	0.5000000	55	=	0.4041913
dl(	10.55995	0.5000000	55	=	0.4491014
gama(beta = 0.6000000 alfa = 5) >	1.011504				
gama	beta	alfa			
dl(	1.011504	0.6000000	5	=	0.0000000E + 00
dl(	1.511504	0.6000000	5	=	2.272913
dl(	2.011504	0.6000000	5	=	4.545825
dl(	2.511504	0.6000000	5	=	6.818738
dl(	3.011504	0.6000000	5	=	9.091650
dl(	3.511504	0.6000000	5	=	11.36456
dl(	4.011504	0.6000000	5	=	13.63748
dl(	4.511504	0.6000000	5	=	15.91039
dl(	5.011504	0.6000000	5	=	18.18330
dl(	5.511504	0.6000000	5	=	20.45621
dl(	6.011504	0.6000000	5	=	22.72912
gama(beta = 0.6000000 alfa = 10) >	1.047016				
gama	beta	alfa			
dl(	1.047016	0.6000000	10	=	0.0000000E + 00
dl(	1.547016	0.6000000	10	=	1.108010
dl(	2.047016	0.6000000	10	=	2.216020
dl(	2.547016	0.6000000	10	=	3.324029
dl(	3.047016	0.6000000	10	=	4.432040
dl(	3.547016	0.6000000	10	=	5.540050
dl(	4.047016	0.6000000	10	=	6.648058

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, ( $d_1 = \Delta L/R_{\epsilon_p}$ ).						
5	dl(	4.547016	0.6000000	10	=	7.756068
	dl(	5.047016	0.6000000	10	=	8.864079
	dl(	5.547016	0.6000000	10	=	9.972089
	dl(	6.047016	0.6000000	10	=	11.08010
	gama(beta = 0.6000000 alfa = 15) >	1.109838				
10	dl(	1.109838	0.6000000	15	=	0.0000000E + 00
	dl(	1.609838	0.6000000	15	=	0.7069143
	dl(	2.109838	0.6000000	15	=	1.413829
	dl(	2.609838	0.6000000	15	=	2.120744
	dl(	3.109838	0.6000000	15	=	2.827658
	dl(	3.609838	0.6000000	15	=	3.534573
15	dl(	4.109838	0.6000000	15	=	4.241487
	dl(	4.609838	0.6000000	15	=	4.948401
	dl(	5.109838	0.6000000	15	=	5.655315
	dl(	5.609838	0.6000000	15	=	6.362230
	dl(	6.109838	0.6000000	15	=	7.069144
	gama(beta = 0.6000000 alfa = 20) >	1.206618				
20	dl(	1.206618	0.6000000	20	=	0.0000000E + 00
	dl(	1.706618	0.6000000	20	=	0.4965974
	dl(	2.206618	0.6000000	20	=	0.9931949
	dl(	2.706618	0.6000000	20	=	1.489792
	dl(	3.206618	0.6000000	20	=	1.986390
25	dl(	3.706618	0.6000000	20	=	2.482987
	dl(	4.206618	0.6000000	20	=	2.979584
	dl(	4.706618	0.6000000	20	=	3.476182
	dl(	5.206618	0.6000000	20	=	3.972780
	dl(	5.706618	0.6000000	20	=	4.469377
	dl(	6.206618	0.6000000	20	=	4.965974
	gama(beta = 0.6000000 alfa = 25) >	1.349856				
30	dl(	1.349856	0.6000000	25	=	0.0000000E + 00
	dl(	1.849856	0.6000000	25	=	0.3623931
	dl(	2.349856	0.6000000	25	=	0.7247862
	dl(	2.849856	0.6000000	25	=	1.087179
35	dl(	3.349856	0.6000000	25	=	1.449572
	dl(	3.849856	0.6000000	25	=	1.811965
	dl(	4.349856	0.6000000	25	=	2.174359
	dl(	4.849856	0.6000000	25	=	2.536751
	dl(	5.349856	0.6000000	25	=	2.899144
	dl(	5.849856	0.6000000	25	=	3.261538
	dl(	6.349856	0.6000000	25	=	3.623930
40	gama(beta = 0.6000000 alfa = 30) >	1.563856				
	dl(	1.563856	0.6000000	30	=	0.0000000E + 00
	dl(	2.063856	0.6000000	30	=	0.2660254
	dl(	2.563856	0.6000000	30	=	0.5320508
	dl(	3.063856	0.6000000	30	=	0.7980763
45	dl(	3.563856	0.6000000	30	=	1.064102
	dl(	4.063856	0.6000000	30	=	1.330127
	dl(	4.563856	0.6000000	30	=	1.596153
	dl(	5.063856	0.6000000	30	=	1.862178
	dl(	5.563856	0.6000000	30	=	2.128203
	dl(	6.063856	0.6000000	30	=	2.394229
	dl(	6.563856	0.6000000	30	=	2.660254
50	gama(beta = 0.6000000 alfa = 35) >	1.900716				
	dl(	1.900716	0.6000000	35	=	0.0000000E + 00
	dl(	2.400717	0.6000000	35	=	0.1910401
	dl(	2.900717	0.6000000	35	=	0.3820800
	dl(	3.400717	0.6000000	35	=	0.5731202
55	dl(	3.900717	0.6000000	35	=	0.7641601
	dl(	4.400716	0.6000000	35	=	0.9552000
	dl(	4.900716	0.6000000	35	=	1.146240
	dl(	5.400716	0.6000000	35	=	1.337280
	dl(	5.900716	0.6000000	35	=	1.528320
	dl(	6.400716	0.6000000	35	=	1.719360
60	dl(	6.900716	0.6000000	35	=	1.910400
	gama(beta = 0.6000000 alfa = 40) >	2.493007				
	dl(	2.493007	0.6000000	40	=	0.0000000E + 00
	dl(	2.993007	0.6000000	40	=	0.1291597
	dl(	3.493007	0.6000000	40	=	0.2583195
65	dl(	3.993007	0.6000000	40	=	0.3874791
	dl(	4.493007	0.6000000	40	=	0.5166388
	dl(	4.993007	0.6000000	40	=	0.6457986

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, ( $d_1 = \Delta L/Re_p$ ).					
dl(	5.493007	0.6000000	40 )=	0.7749582	
dl(	5.993007	0.6600000	40 )=	0.9041179	
dl(	6.493007	0.6000000	40 )=	1.033278	
dl(	6.993007	0.6000000	40 )=	1.162437	
dl(	7.493007	0.6000000	40 )=	1.291597	
gama(beta = 0.6000000 alfa = 45) > 3.800942					
gama	beta	alfa			
dl(	3.800942	0.6000000	45 )=	0.0000000E + 00	
d1)	4.300942	0.6000000	45 )=	7.5736046E - 02	
dl(	4.800942	0.6000000	45 )=	0.1514720	
dl(	5.300942	0.6000000	45 )=	0.2272079	
dl(	5.800942	0.6000000	45 )=	0.3029439	
dl(	6.300942	0.6000000	45 )=	0.3786799	
dl(	6.800942	0.6000000	45 )=	0.4544158	
dl(	7.300942	0.6000000	45 )=	0.5301518	
dl(	7.800942	0.6000000	45 )=	0.6058878	
dl(	8.300942	0.6000000	45 )=	0.6816237	
dl(	8.800942	0.6000000	45 )=	0.7573596	
gama(beta = 0.6000000 alfa = 50) > 9.228890					
gama	beta	alfa			
dl(	9.228890	0.6000000	50 )=	0.0000000E + 00	
dl(	9.728890	0.6000000	50 )=	2.7927648E - 02	
dl(	10.22889	0.6000000	50 )=	5.5855297E - 02	
dl(	10.72889	0.6000000	50 )=	8.3782844E - 02	
dl(	11.22889	0.6000000	50 )=	0.1117105	
dl(	11.72889	0.6000000	50 )=	0.1396381	
dl(	12.22889	0.6000000	50 )=	0.1675658	
dl(	12.72889	0.6000000	50 )=	0.1954933	
dl(	13.22889	0.6000000	50 )=	0.2234210	
dl(	13.72889	0.6000000	50 )=	0.2513486	
dl(	14.22889	0.6000000	50 )=	0.2792763	
gama(beta = 0.7000000 alfa = 5) > 1.017952					
gama	beta	alfa			
dl(	1.017952	0.7000000	5 )=	0.0000000E + 00	
dl(	1.517952	0.7000000	5 )=	1.699228	
dl(	2.017952	0.7000000	5 )=	3.398454	
dl(	2.517952	0.7000000	5 )=	5.097681	
dl(	3.017952	0.7000000	5 )=	6.796908	
dl(	3.517952	0.7000000	5 )=	8.496135	
dl(	4.017952	0.7000000	5 )=	10.19536	
dl(	4.517952	0.7000000	5 )=	11.89459	
dl(	5.017952	0.7000000	5 )=	13.59381	
dl(	5.517952	0.7000000	5 )=	15.29304	
dl(	6.017952	0.7000000	5 )=	16.99227	
gama(beta = 0.7000000 alfa = 10) > 1.074112					
gama	beta	alfa			
dl(	1.074112	0.7000000	10 )=	0.0000000E + 00	
dl(	1.574112	0.7000000	10 )=	0.8200716	
dl(	2.074112	0.7000000	10 )=	1.640143	
dl(	2.574112	0.7000000	10 )=	2.460214	
dl(	3.074112	0.7000000	10 )=	3.280286	
dl(	3.574112	0.7000000	10 )=	4.100357	
dl(	4.074112	0.7000000	10 )=	4.920428	
dl(	4.574112	0.7000000	10 )=	5.740499	
dl(	5.074112	0.7000000	10 )=	6.560570	
dl(	5.574112	0.7000000	10 )=	7.380642	
dl(	6.074112	0.7000000	10 )=	8.200713	
gama(beta = 0.7000000 alfa = 15) > 1.176332					
gama	beta	alfa			
dl(	1.176332	0.7000000	15 )=	0.0000000E + 00	
dl(	1.676332	0.7000000	15 )=	0.5137293	
dl(	2.176332	0.7000000	15 )=	1.027459	
dl(	2.676332	0.7000000	15 )=	1.541188	
dl(	3.176332	0.7000000	15 )=	2.054917	
dl(	3.676332	0.7000000	15 )=	2.568646	
dl(	4.176332	0.7000000	15 )=	3.082376	
dl(	4.676332	0.7000000	15 )=	3.596105	
dl(	5.176332	0.7000000	15 )=	4.109834	
dl(	5.676332	0.7000000	15 )=	4.623564	
dl(	6.176332	0.7000000	15 )=	5.137293	
gama(beta = 0.7000000 alfa = 20) > 1.341623					
gama	beta	alfa			
dl(	1.341623	0.7000000	20 )=	0.0000000E + 00	
dl(	1.841623	0.7000000	20 )=	0.3504074	
dl(	2.341623	0.7000000	20 )=	0.7008147	
dl(	2.841623	0.7000000	20 )=	1.051222	
dl(	3.341623	0.7000000	20 )=	1.401629	

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, ( $d_1 = \Delta L/Re_p$ ).					
5 dl(	3.841623	0.7000000	20 )=	1.752036	
dl(	4.341623	0.7000000	20 )=	2.102443	
dl(	4.841623	0.7000000	20 )=	2.452851	
dl(	5.341623	0.7000000	20 )=	2.803258	
dl(	5.841623	0.7000000	20 )=	3.153665	
dl(	6.341623	0.7000000	20 )=	3.504072	
10 gama(beta = 0.7000000 alfa = 25) > 1.606009					
gama	beta	alfa			
dl(	1.606009	0.7000000	25 )=	0.0000000E + 00	
dl(	2.106009	0.7000000	25 )=	0.2440831	
dl(	2.606009	0.7000000	25 )=	0.4881659	
dl(	3.106009	0.7000000	25 )=	0.7322490	
dl(	3.606009	0.7000000	25 )=	0.9763318	
dl(	4.106009	0.7000000	25 )=	1.220415	
dl(	4.606009	0.7000000	25 )=	1.464498	
dl(	5.106009	0.7000000	25 )=	1.708581	
dl(	5.606009	0.7000000	25 )=	1.952664	
dl(	6.106009	0.7000000	25 )=	2.196746	
dl(	6.606009	0.7000000	25 )=	2.440830	
20 gama(beta = 0.7000000 alfa = 30) > 2.054056					
gama	beta	alfa			
dl(	2.054056	0.7000000	30 )=	0.0000000E + 00	
dl(	2.554056	0.7000000	30 )=	0.1660255	
dl(	3.054056	0.7000000	30 )=	0.3320508	
dl(	3.554056	0.7000000	30 )=	0.4980763	
dl(	4.054056	0.7000000	30 )=	0.6641017	
dl(	4.554056	0.7000000	30 )=	0.8301272	
dl(	5.054056	0.7000000	30 )=	0.9961525	
dl(	5.554056	0.7000000	30 )=	1.162178	
dl(	6.054056	0.7000000	30 )=	1.328203	
dl(	6.554056	0.7000000	30 )=	1.494229	
30 dl(	7.054056	0.7000000	30 )=	1.660254	
gama(beta = 0.7000000 alfa = 35) > 2.932765					
gama	beta	alfa			
dl(	2.932765	0.7000000	35 )=	0.0000000E + 00	
dl(	3.432765	0.7000000	35 )=	0.1038678	
dl(	3.932765	0.7000000	35 )=	0.2077354	
dl(	4.432765	0.7000000	35 )=	0.3116030	
dl(	4.932765	0.7000000	35 )=	0.4154705	
dl(	5.432765	0.7000000	35 )=	0.5193383	
dl(	5.932765	0.7000000	35 )=	0.6232059	
dl(	6.432765	0.7000000	35 )=	0.7270735	
dl(	6.932765	0.7000000	35 )=	0.8309411	
40 dl(	7.432765	0.7000000	35 )=	0.9348087	
gama(beta = 0.7000000 alfa = 40) > 5.379220					
gama	beta	alfa			
dl(	5.379220	0.7000000	40 )=	0.0000000E + 00	
dl(	5.879220	0.7000000	40 )=	5.1373534E - 02	
dl(	6.379220	0.7000000	40 )=	0.1027469	
45 dl(	6.879220	0.7000000	40 )=	0.1541205	
dl(	7.379220	0.7000000	40 )=	0.2054938	
dl(	7.879220	0.7000000	40 )=	0.2568674	
dl(	8.379220	0.7000000	40 )=	0.3082408	
dl(	8.879220	0.7000000	40 )=	0.3596143	
dl(	9.379220	0.7000000	40 )=	0.4109877	
50 dl(	9.879220	0.7000000	40 )=	0.4623612	
dl(	10.379220	0.7000000	40 )=	0.5137346	
gama(beta = 0.7000000 alfa = 45) > 50.24860					
gama	beta	alfa			
dl(	50.24860	0.7000000	45 )=	0.0000000E + 00	
dl(	50.74860	0.7000000	45 )=	5.0252676E - 03	
55 dl(	51.24860	0.7000000	45 )=	1.0050535E - 02	
dl(	51.74860	0.7000000	45 )=	1.5075803E - 02	
dl(	52.24860	0.7000000	45 )=	2.0101070E - 02	
dl(	52.74860	0.7000000	45 )=	2.5126338E - 02	
dl(	53.24860	0.7000000	45 )=	3.0151606E - 02	
dl(	53.74860	0.7000000	45 )=	3.5176873E - 02	
dl(	54.24860	0.7000000	45 )=	4.0202141E - 02	
dl(	54.74860	0.7000000	45 )=	4.5227408E - 02	
dl(	55.24860	0.7000000	45 )=	5.0252676E - 02	
gama(beta = 0.8000000 alfa = 5) > 1.030974					
gama	beta	alfa			
dl(	1.030974	0.8000000	5 )=	0.0000000E + 00	
dl(	1.530974	0.8000000	5 )=	1.125542	
65 dl(	2.030974	0.8000000	5 )=	2.251082	
dl(	2.530974	0.8000000	5 )=	3.376623	

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, ( $d_1 = \Delta L/R_{\epsilon_p}$ ).						
dl(	3.030974	0.8000000	5 )=	4.502163		
dl(	3.530974	0.8000000	5 )=	5.627705		
dl(	4.030974	0.8000000	5 )=	6.753245		
dl(	4.530974	0.8000000	5 )=	7.878787		
dl(	5.030974	0.8000000	5 )=	9.004327		
dl(	5.530974	0.8000000	5 )=	10.12987		
dl(	6.030974	0.8000000	5 )=	11.25541		
gama(beta = 0.8000000 alfa = 10) >	1.130530					
gama	beta	alfa				
dl(	1.130530	0.8000000	10 )=	0.0000000E + 00		
dl(	1.630530	0.8000000	10 )=	0.53211329		
dl(	2.130530	0.8000000	10 )=	1.064265		
dl(	2.630530	0.8000000	10 )=	1.596398		
dl(	3.130530	0.8000000	10 )=	2.128531		
dl(	3.630530	0.8000000	10 )=	2.660663		
dl(	4.130530	0.8000000	10 )=	3.192796		
dl(	4.630530	0.8000000	10 )=	3.724929		
dl(	5.130530	0.8000000	10 )=	4.257061		
dl(	5.630530	0.8000000	10 )=	4.789194		
dl(	6.130530	0.8000000	10 )=	5.321326		
gama(beta = 0.8000000 alfa = 15) >	1.322975					
gama	beta	alfa				
dl(	1.322975	0.8000000	15 )=	0.0000000E + 00		
dl(	1.822975	0.8000000	15 )=	0.3205443		
dl(	2.322975	0.8000000	15 )=	0.6410881		
dl(	2.822975	0.8000000	15 )=	0.9616324		
dl(	3.322975	0.8000000	15 )=	1.282176		
dl(	3.822975	0.8000000	15 )=	1.602720		
dl(	4.322975	0.8000000	15 )=	1.923264		
dl(	4.822975	0.8000000	15 )=	2.243809		
dl(	5.322975	0.8000000	15 )=	2.564352		
dl(	5.822975	0.8000000	15 )=	2.884897		
dl(	6.322975	0.8000000	15 )=	3.205441		
gama(beta = 0.8000000 alfa = 20) >	1.669916					
gama	beta	alfa				
dl(	1.669916	0.8000000	20 )=	0.0000000E + 00		
dl(	2.169916	0.8000000	20 )=	0.2042170		
dl(	2.669916	0.8000000	20 )=	0.4084340		
dl(	3.169916	0.8000000	20 )=	0.6126506		
dl(	3.669916	0.8000000	20 )=	0.8168676		
dl(	4.169916	0.8000000	20 )=	1.021085		
dl(	4.669916	0.8000000	20 )=	1.225302		
dl(	5.169916	0.8000000	20 )=	1.429518		
dl(	5.669916	0.8000000	20 )=	1.633735		
dl(	6.169916	0.8000000	20 )=	1.837952		
dl(	6.669916	0.8000000	20 )=	2.042169		
gama(beta = 0.8000000 alfa = 25) >	2.344067					
gama	beta	alfa				
dl(	2.344067	0.8000000	25 )=	0.0000000E + 00		
dl(	2.844067	0.8000000	25 )=	0.1257728		
dl(	3.344067	0.8000000	25 )=	0.2515459		
dl(	3.844067	0.8000000	25 )=	0.3773187		
dl(	4.344068	0.8000000	25 )=	0.5030918		
dl(	4.844068	0.8000000	25 )=	0.6288645		
dl(	5.344068	0.8000000	25 )=	0.7546374		
dl(	5.844068	0.8000000	25 )=	0.8804101		
dl(	6.344068	0.8000000	25 )=	1.006183		
dl(	6.844068	0.8000000	25 )=	1.131956		
dl(	7.344068	0.8000000	25 )=	1.257729		
gama(beta = 0.8000000 alfa = 30) >	4.029140					
gama	beta	alfa				
dl(	4.029140	0.8000000	30 )=	0.0000000E + 00		
dl(	4.529140	0.8000000	30 )=	6.6025421E - 02		
dl(	5.029140	0.8000000	30 )=	0.1320508		
dl(	5.529140	0.8000000	30 )=	0.1980761		
dl(	6.029140	0.8000000	30 )=	0.2641015		
dl(	6.529140	0.8000000	30 )=	0.3301269		
dl(	7.029140	0.8000000	30 )=	0.3961523		
dl(	7.529140	0.8000000	30 )=	0.4621775		
dl(	8.029140	0.8000000	30 )=	0.5282030		
dl(	8.529140	0.8000000	30 )=	0.5942284		
dl(	9.029140	0.8000000	30 )=	0.6602538		
gama(beta = 0.8000000 alfa = 35) >	14.74223					
gama	beta	alfa				
dl(	14.74223	0.8000000	35 )=	0.0000000E + 00		
dl(	15.24223	0.8000000	35 )=	1.6695250E - 02		
dl(	15.74223	0.8000000	35 )=	3.3390671E - 02		

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, ( $d_1 = \Delta L/R_{\epsilon_p}$ ).						
5	dl(	16.24223	0.8000000	35 )=	5.0085921E - 02	
	dl(	16.74223	0.8000000	35 )=	6.6781171E - 02	
	dl(	17.24223	0.8000000	35 )=	8.3476588E - 02	
	dl(	17.74223	0.8000000	35 )=	0.1001718	
	dl(	18.24223	0.8000000	35 )=	0.1168671	
	dl(	18.74223	0.8000000	35 )=	0.1335623	
10	dl(	19.24223	0.8000000	35 )=	0.1502578	
	dl(	19.74223	0.8000000	35 )=	0.1669530	
	gama(beta = 0.9000000 alfa = 5) >	1.071069				
	gama	beta	alfa			
	dl(	1.071069	0.9000000	5 )=	0.0000000E + 00	
	dl(	1.571069	0.9000000	5 )=	0.5518552	
15	dl(	2.071069	0.9000000	5 )=	1.103712	
	dl(	2.571069	0.9000000	5 )=	1.655567	
	dl(	3.071069	0.9000000	5 )=	2.207422	
	dl(	3.571069	0.9000000	5 )=	2.759278	
	dl(	4.071069	0.9000000	5 )=	3.311134	
	dl(	4.571069	0.9000000	5 )=	3.862989	
20	dl(	5.071069	0.9000000	5 )=	4.414845	
	dl(	5.571069	0.9000000	5 )=	4.966701	
	dl(	6.071069	0.9000000	5 )=	5.518556	
	gama(beta = 0.9000000 alfa = 10) >	1.319999				
	gama	beta	alfa			
	dl(	1.319999	0.9000000	10 )=	0.0000000E + 00	
	dl(	1.819999	0.9000000	10 )=	0.2441943	
25	dl(	2.319999	0.9000000	10 )=	0.4883885	
	dl(	2.819999	0.9000000	10 )=	0.7325828	
	dl(	3.319999	0.9000000	10 )=	0.9767771	
	dl(	3.819999	0.9000000	10 )=	1.220971	
	dl(	4.319999	0.9000000	10 )=	1.465166	
	dl(	4.819999	0.9000000	10 )=	1.709360	
30	dl(	5.319999	0.9000000	10 )=	1.953554	
	dl(	5.819999	0.9000000	10 )=	2.197748	
	dl(	6.319999	0.9000000	10 )=	2.441943	
	gama(beta = 0.9000000 alfa = 15) >	1.914492				
	gama	beta	alfa			
35	dl(	1.914492	0.9000000	15 )=	0.0000000E + 00	
	dl(	2.414492	0.9000000	15 )=	0.1273588	
	dl(	2.914492	0.9000000	15 )=	0.2547180	
	dl(	3.414492	0.9000000	15 )=	0.3820768	
	dl(	3.914492	0.9000000	15 )=	0.5094356	
40	dl(	4.414492	0.9000000	15 )=	0.6367944	
	dl(	4.914492	0.9000000	15 )=	0.7641537	
	dl(	5.414492	0.9000000	15 )=	0.8915125	
	dl(	5.914492	0.9000000	15 )=	1.018871	
	dl(	6.414492	0.9000000	15 )=	1.146230	
	dl(	6.914492	0.9000000	15 )=	1.273589	
	gama(beta = 0.9000000 alfa = 20) >	3.652381				
	gama	beta	alfa			
45	dl(	3.652381	0.9000000	20 )=	0.0000000E + 00	
	dl(	4.152381	0.9000000	20 )=	5.8026921E - 02	
	dl(	4.652381	0.9000000	20 )=	0.1160535	
	dl(	5.152381	0.9000000	20 )=	0.1740804	
	dl(	5.652381	0.9000000	20 )=	0.2321070	
50	dl(	6.152381	0.9000000	20 )=	0.2901340	
	dl(	6.652381	0.9000000	20 )=	0.3481605	
	dl(	7.152381	0.9000000	20 )=	0.4061875	
	dl(	7.652381	0.9000000	20 )=	0.4642141	
	dl(	8.152381	0.9000000	20 )=	0.5222410	
	dl(	8.652381	0.9000000	20 )=	0.5802675	
55	gama(beta = 0.9000000 alfa = 25) >	26.48351				
	gama	beta	alfa			
	dl(	26.48351	0.9000000	25 )=	0.0000000E + 00	
	dl(	26.98351	0.9000000	25 )=	7.4627930E - 03	
	dl(	27.48351	0.9000000	25 )=	1.4925586E - 02	
	dl(	27.98351	0.9000000	25 )=	2.2388378E - 02	
60	dl(	28.48351	0.9000000	25 )=	2.9851172E - 02	
	dl(	28.98351	0.9000000	25 )=	3.7313964E - 02	
	dl(	29.48351	0.9000000	25 )=	4.4776756E - 02	
	dl(	29.98351	0.9000000	25 )=	5.2239552E - 02	
	dl(	30.48351	0.9000000	25 )=	5.9702344E - 02	
	dl(	30.98351	0.9000000	25 )=	6.7165136E - 02	
65	dl(	31.48351	0.9000000	25 )=	7.4627928E - 02	Z

I claim:

1. A method of creating a seal that is effective across a range of temperatures, including cryogenic temperatures, comprising the steps of:

- a) selecting a sealing spacer having a desired coefficient of thermal expansion and tube ends having different coefficients of thermal expansion therefrom, said spacer and said tube ends also having shapes complementary to each other such that when said tube ends are brought into contact with said spacer, a sealed sloped engagement results yielding sloped-surface sealing; and
- b) placing said spacer in contact with said tube ends such that a sealed sloped engagement yielding sloped-surface sealing is accomplished that maintains the seal across a range of various temperatures, including cryogenic temperatures.

2. The method according to claim 1, wherein said sealing spacer is placed in contact with said tube ends by using a housing nut.

3. The method according to claim 2, wherein said housing nut, during cooling, contracts and thereby forces said tube ends toward each other, thereby maintaining the seal at various temperatures, including cryogenic temperatures.

4. The method according to claim 3, wherein said housing nut has a larger coefficient of thermal expansion than said tube ends.

5. A method of joining tube ends to provide an effective seal across a range of temperatures, including cryogenic temperatures, wherein said tube ends each have a sloped contact surface, said method comprising the steps of

- a) selecting a sealing spacer having a larger coefficient of thermal expansion than said tube ends, and a shape complementary thereto; and
- b) placing said sealing spacer in contact with each said sloped contact surface so that during cooling, as said sealing spacer contracts, a sealed engagement with each of said sloped contact surfaces yielding sloped-surface sealing is maintained.

6. The method according to claim 5, wherein each of said sloped contact surfaces is on an outer portion of each of said tube ends.

7. The method according to claim 6, wherein said sealing spacer is placed in contact with said sloped contact surfaces by using a housing nut.

8. The method according to claim 7, wherein said housing nut, during cooling, contracts and thereby forces said tube ends toward each other, thereby maintaining the formation and maintenance of a leak-free seal at various temperatures, including cryogenic temperatures.

9. The method according to claim 8, wherein said housing nut has a larger coefficient of thermal expansion than said tube ends.

10. The method according to claim 5, wherein said sealing spacer is placed in contact with said sloped contact surfaces by using a housing nut.

11. The method according to claim 10, wherein said housing nut, during cooling, contracts and thereby forces said tube ends toward each other, thereby maintaining the formation and maintenance of a leak-free seal at various temperatures, including cryogenic temperatures.

12. The method according to claim 11, wherein said housing nut has a larger coefficient of thermal expansion than said tube ends.

13. A cryogenic tube seal comprising a first coupling member having a first sloped contact surface on an outer portion of said member; a second coupling member having a second sloped contact surface on an outer portion of said member; and sealing means for establishing and maintaining sloped-surface sealing between said coupling members at cryogenic temperatures at least as low as about 77K without resulting in inelastic deformation of either of said sloped contact surfaces or said sealing means.

14. The cryogenic tube seal, according to claim 13, wherein said sealing means comprises a sealing spacer having a greater coefficient of thermal expansion than each of said coupling members, wherein said sealing spacer contacts said first contact surface and said second contact surface, and wherein said sealing means also comprises a housing nut selectively engaged with said first coupling member and said second coupling member, wherein said housing nut has a greater coefficient of thermal expansion than each of said coupling members.

15. The seal, according to claim 14, wherein said sealing spacer is an O-ring spacer.

\* \* \* \* \*

UNITED STATES PATENT AND TRADEMARK OFFICE  
**CERTIFICATE OF CORRECTION**

5,628,517

PATENT NO. :

DATED : May 13, 1997

INVENTOR(S) :

Hall *et al.*

It is certified that error appears in the above-indentified patent and that said Letters Patent is hereby corrected as shown below:

Column 1: line 40: "ting" should read --ring--; line 41: "ting" should read --ring--.

Column 3: line 48: "a housing nut.." should read --a housing nut.--

Column 5: line 17: "tube end :12 into" should read --tube end 22 into--;

line 54: "[ $\alpha$  +O tan<sup>1</sup> (...)" should read --[ $\alpha$  + tan<sup>1</sup> (...)--.

Column 6: line 46: "and  $\Delta\tau' = \Delta L' \tan\alpha$ ," should read --and  $\Delta\tau' = \Delta L' \tan\alpha$ ,--;

line 54: "where  $\Delta r = r_1 r_2$ " should read --where  $\Delta r = r_1 - r_2$ ;

lines 65&55: "where  $\epsilon$  and  $\epsilon_p$  are" should read --where  $\epsilon_o$  and  $\epsilon_p$  are--.

Column 7: line 6: "Let  $\gamma = \epsilon_o/\epsilon_p$ , and  $\beta = 4_i/R$ ," should read --Let  $\gamma = \epsilon_o/\epsilon_p$ , and  
 $\beta = r_1/R$ ,--.

Column 27: line 23: "the seal various" should read --the seal at various--.

Signed and Sealed this

Nineteenth Day of August, 1997

Attest:



BRUCE LEHMAN

Attesting Officer

Commissioner of Patents and Trademarks